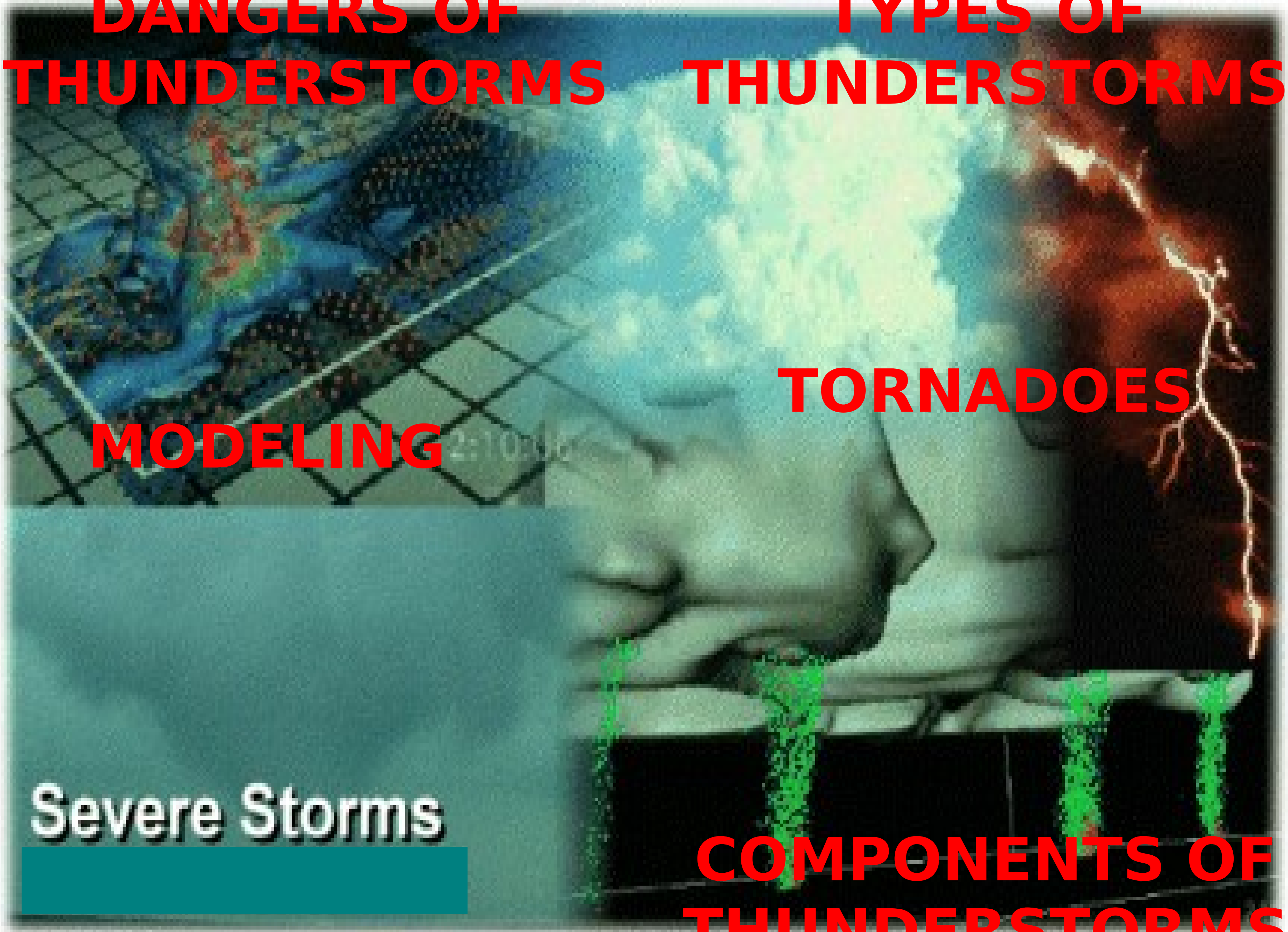
DANGERS OF THUNDERSTORMS

TYPES OF THUNDERSTORMS



TORNADOES

MODELING

COMPONENTS OF THUNDERSTORMS

Lightning

a visible electric discharge produced by thunderstorms

Let's review the destructive and deadly thunderstorm elements before introducing the thunderstorm spectrum. By definition, all thunderstorms contain lightning. This photograph shows light

cumulonimbus cloud.

In most years it is the thunderstorm's greatest killer. A possible contributing reason for this is that lightning victims frequently are struck before or just after the occurrence of precipitation at their location. Many

Flash Floods and Hail

property and personal devastation

Cases involving either slow-moving thunderstorms or a series of storms which move repeatedly across the same area (sometimes called train-echo storms) frequently result in flash flooding. The total number of flash flood deaths has exce… uring the last several decade…

Two factors seem to be responsible for this: public apathy regarding the flash flood threat and increased urbanization. When concrete replaces soil, rain water will run off rather than soak in. Flash flood producing rainfall has made this type of dramatic rescue attempt (pictured above) all too

Another danger associated with thunderstorms, especially to personal property, is hail. This hailfall occurred in Altus, Oklahoma in 1982 and was accompanied by several tornadoes. Hail causes more monetary loss than any other type of thunderstorm-spawned s

Annually, the United States alone suffers about one billion dollars in crop damage from hail. Hail rarely kills people, but these were hollow words in China in May, 1986 when 100 people were killed, 9,000 injured, and

Outflow

winds flowing outward from thunderstorms

Thunderstorm winds also cause widespread damage and occasional fatalities. Thunderstorm "straight-line" winds originate from rain-cooled air that descends with accompanying precipitation. This central Texas windstorm, approaching from the west, was packing 80 MPH winds behind the spectacular appearing gust front. The same thunderstorm earlier produced several small tornadoes, grapefruit size ha

(Looking west from about 5

After the thunderstorm gust front passes and before precipitation, if any, arrives, blowing dust often is kicked up by thunderstorm induced winds. The amount of dust depends on soil type, soil

Note the aviation "wind sock" in the photograph. Winds were estimated to be about 50 MPH at this time along the Texas-New Mexico border east of Hobbs, New Mexico. Severe thunderstorm winds are especially dangerous to aviation interests, particularly aircraft which are c

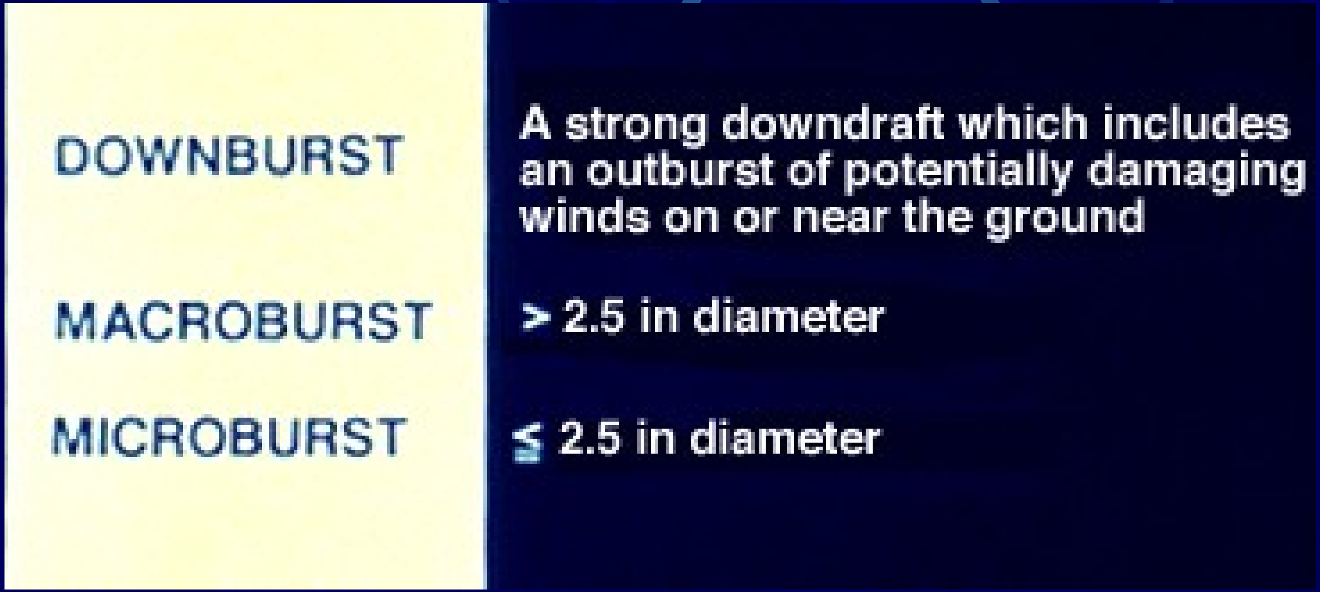
Many western US storms, such as this one in southern Colorado, have extremely high bases and low tops. Don't let the weak appearance fool you! Some of the "dry storms" can produce dangerous microbursts and copious amounts of fire-setting lightning

Recent research has shown that microbursts, both "dry" ones such as this (actually some very light rain may fall with a dry microburst) and "wet" ones frequently are the cause of wind shear induced aircraft accidents.

Downbursts

severe localized downdrafts

Damaging thunderstorm winds have been termed downbursts by renowned severe storm researcher Dr. Ted Fujita. Dr. Fujita further classifies these events as macrobursts (greater than 2.5 miles in diameter) and microbursts (less than 2.5 miles in diameter).



DOWNBURST	A strong downdraft which includes an outburst of potentially damaging winds on or near the ground
MACROBURST	> 2.5 in diameter
MICROBURST	≤ 2.5 in diameter

Generally, a macroburst is on the scale of the entire cold air outflow field of a thunderstorm or a group of thunderstorms; whereas the microburst is a sub-thunderstorm scale outflow feature. This is a southward view from with[...]bedded within a macro[...]

The transition line from ragged to smooth cloud texture, to the left and above the microburst, is where the right to left-advancing macroburst meets cloud base. This is the leading edge of the thunderstorm gust front ahead of a line of thunderstorms. Immediately behind the gust front and to the right side of the highway, the microburst has reached ground and is in the process of "curling" over the highway. Estimated

Tornado
es

violently rotating
columns of air

The last severe weather element is the tornado. Defined as a violently rotating column of air in contact with the ground and pendent from a cumulonimbus cloud, tornadoes are capable of inf

They can be categorized as "weak", "strong", and "violent"; with weak tornadoes often having a thin, rope-like appearance, as exhibited by this tornado near Dawn, Texas (looking west from about 1 mile). About 7 in 10 tornadoes

The typical strong tornado often has what is popularly considered a more "classic" funnel-shaped cloud associated with the whirling updraft. Rotating wind speeds vary from 110 to 200 MPH.

Nearly 3 in 10 tornadoes are strong, such as this twister on the plains of North Dakota. Looking northeast, note the spiraling inflow cloud, probably a tail cloud, feeding into the tornado. An important safety consideration is that weak and strong tornadoes, by definition, do not level well-built homes. Thus, a secure home will offer shelter from

Only violent tornadoes are capable of leveling a well-anchored, solidly constructed home. Fortunately, less than 2 percent of all tornadoes reach the 200+ MPH violent category. Furthermore, most violent tornadoes only produce home-leveling damage within a very small portion of their overall damage swath. Less than 5 percent of the 5,000 affected homes in Wichita Falls, Texas were leveled by

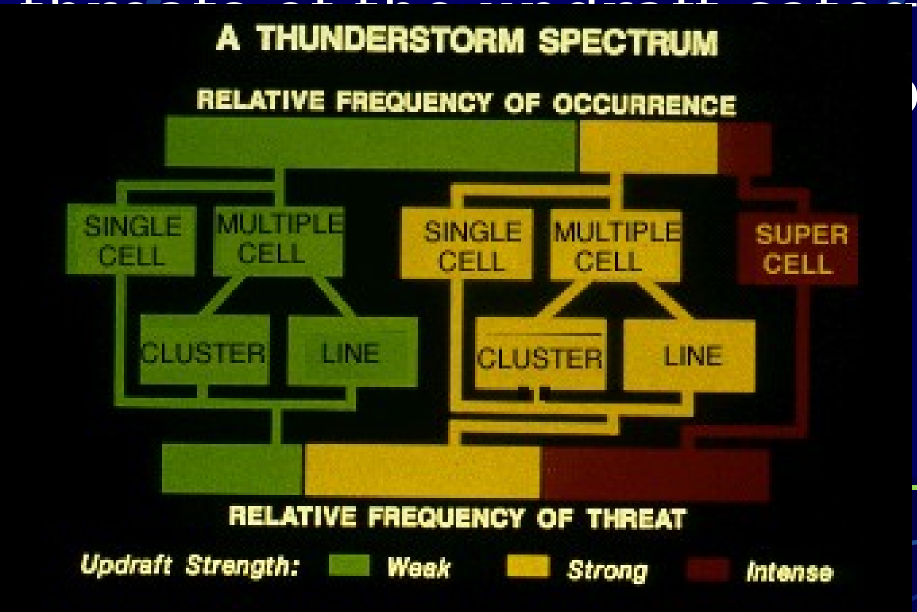
south from about 5 miles).

Note the huge, circular wall cloud above the tornado. This feature is probably close both in size and location to the parent rotating updraft (called a mesocyclone) which has spawned the violent tornado. Strong and violent tornadoes are usually associated with

Types of Thunderstorms

single cell, multicell clusters, multicell lines and supercells

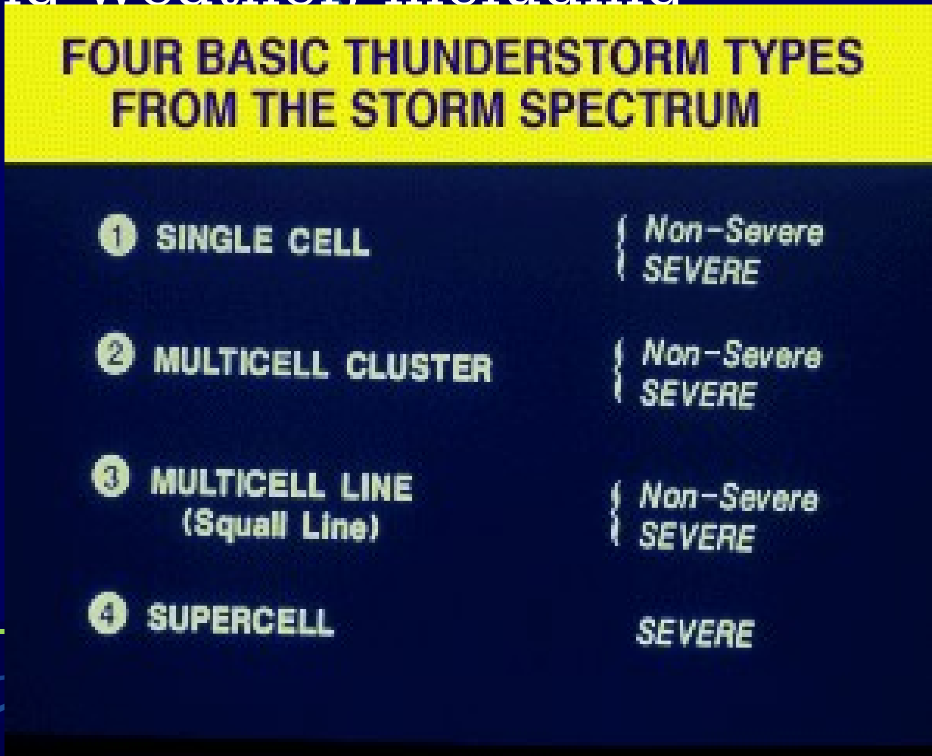
The array of thunderstorms within the spectrum reflects our current scientific understanding. Thus, while the spectrum is very useful, it is neither perfect nor a final solution. Nevertheless, arrangement of storms within the spectrum is dependent on updraft strength, here represented by different colors; relative frequencies of these updraft strength categories, as indicated by differing lengths on the upper bar graph; and relative threats of the updraft categories, here represented by ... bar graph.



Thus, while a "strong" updraft is less common than a "weak" updraft, the relative threat to life and property is greater with the "strong" updraft storm. Similarly, "intense" updraft storms are quite rare but inflict a disproportionate amount of damage and personal injury.

The breakdown into single cell, multicell, and supercell covers the major storm types within the spectrum. One "cell" denotes one updraft/downdraft couplet. Thus, there are several updrafts and downdrafts in close proximity with a multicell storm. Multicell storms can be broken down further into the categories of multicell line and multicell cluster storms. The "intense" updraft storm is almost invariably the supercell, a storm capable of producing the most devastating weather, including violent tornadoes.

With the two multicell storm categories, we have defined four basic storm types from the thunderstorm spectrum. The supercell is always severe, whereas the others can be non-severe or severe. We stress that a "severe" storm is a somewhat arbitrary National Weather Service definition of a storm with



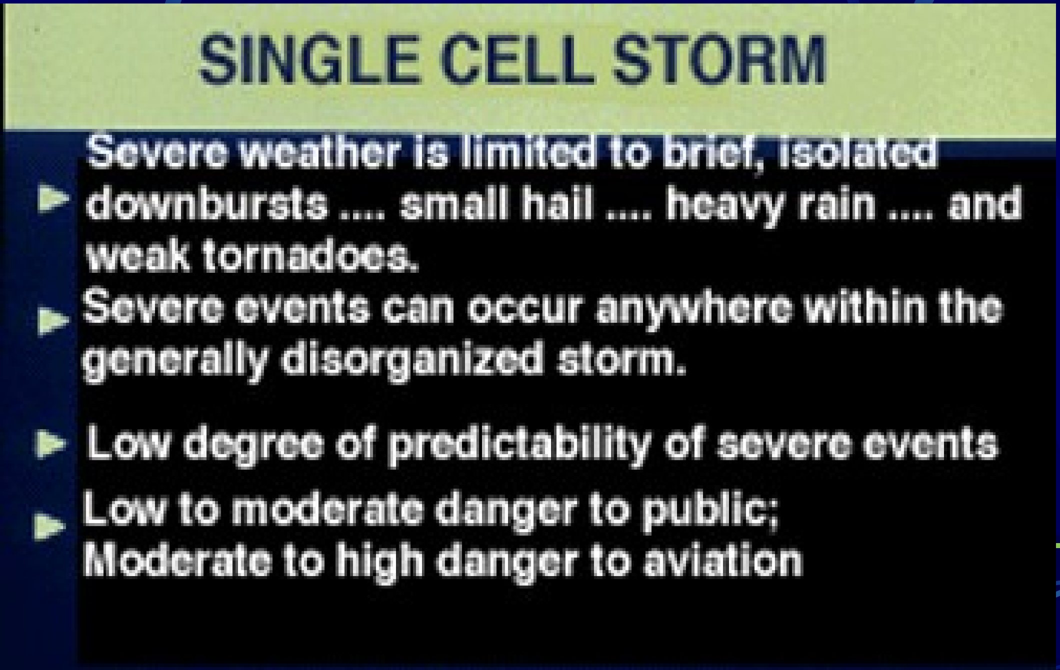
Before reviewing these storms, it is important to emphasize that real thunderstorms do not always fit neatly into the categories we have just described. Research has suggested that the most basic distinction among storm types is between supercells and everything else, the so-called "ordinary" cells.

Non-supercell storms consist of one or more ordinary cells, and we have described three basic ways in which ordinary cells commonly occur: as isolated cells, as clusters of cells, and in lines of cells. Even though real storms can have physical traits that cross the boundaries of these categories, this classification scheme still has considerable value. This is because the intensity and type of weather events produced by a storm tends to be dependent on which category it fits most closely. We

Single Cell Thunderstorms

also known as pulse thunderstorms

Single cell storms typically do not produce severe weather and usually last for 20-30 minutes. Also known as pulse storms, single cell storms seem quite random (perhaps because of our lack of understanding) in the production of brief severe events such as downbursts, hail, some heavy rainfall, and occasional weak tornadoes



The "degree of predictability" is extremely low as forecasters are never quite sure which storm will produce severe weather and from which portion of that storm the severe events will occur. However, the

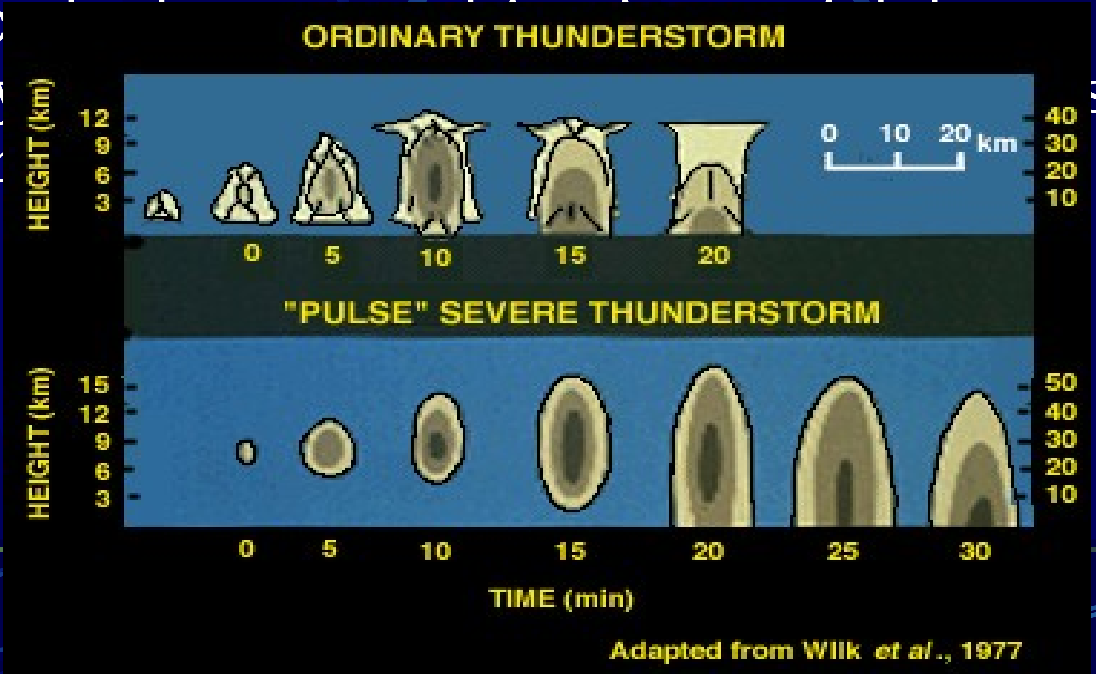
This is a single cell storm, looking east from about 15 miles. The storm was moving east (into the photo). Some of the anvil cloud has been left behind the storm, but the greater portion of the anvil is blowing off in advance of the storm and is not observable from this perspective. (May storm in the Texas Panhandle near Amarillo.)

True single cell storms are relatively rare since even the weakest of storms usually occur as multicell updraft events. Some single cell thunderstorms are called "air mass" storms. This late May storm in Oklahoma, looking northeast from about 20 miles, occurred

Evolution of a Single Cell Storm

typical lifespan less than one hour

The upper sequence depicts the life cycle of a non-severe single cell storm in weak wind shear, with white cloud shapes and gray shades of progressively heavier radar reflectivity. Note the quick collapse of the rainy downdraft through the updraft. The bottom sequence depicts the radar history of the severe pulse storm. Note that the initial radar echo in the pulse storm develops at higher levels than in the non-severe single cell storms. Stronger radar reflectivities aloft with the pulse storm casc … of severe weather, possibly … st before storm dissipation



Although both non-severe and severe single cell storms typically occur in weakly-sheared, summer atmospheres, the pulse storm usually occurs in a more unstable environment. Its stronger updraft allows for a slightly longer lifetime. Severe storm radar detection methods such as the Lemon Technique, developed for vertically-sheared environments, will not work very well with pulse storms. The exception to this is the case where the radar operator detects unusually strong mid-level reflectivities prior to updraft collapse.

This is another single cell storm with tops near 40,000 feet, but on a day with virtually no vertical wind shear. Contrast the height of the cloud base with that in the previous photo. This storm had a much higher base, about 1/5 of the way to the storm top, or approximately 8,000 feet above the ground. The temperature and dew point temperature on this August day were 102 and 61

Storms that occur with 30 to 50 degree surface temperature/dew point spreads have relatively high microburst potential. (This is not to say that environments without such huge spreads will not produce microbursts!) This combination of surface observations and high-based Cbs should serve as "red flags" to pilots and aviation weather forecasters. Several short-lived storms that occurred in the Fort

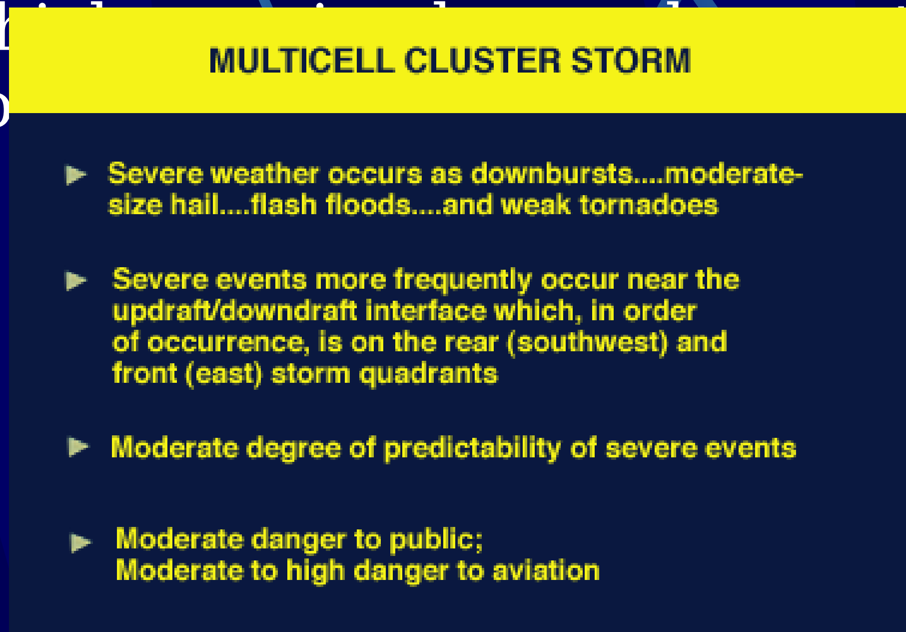
Multicell Cluster Storms

a cluster of storms in varying stages of development

A multicell cluster consists of a group of cells moving as a single unit, with each cell in a different stage of the thunderstorm life cycle. As the multicell cluster evolves, individual cells take turns at being the most dominant. New cells tend to form along the upwind (typically western or southwestern) edge of the cluster, with mature cells located at the center and dissipating cells found along the downwind (east or northeast) portion of the cluster.

Multicell cluster storms frequently look similar to the one pictured in the photograph below, (assuming that low visibilities and/or intervening clouds, trees, or hills do not obscure the view). Looking north from about 10 miles, note the three distinct updraft towers at the left (west) portion of the storm. The heaviest precipitation likely falls beneath the highest cloud top. The right (east) side of the complex is

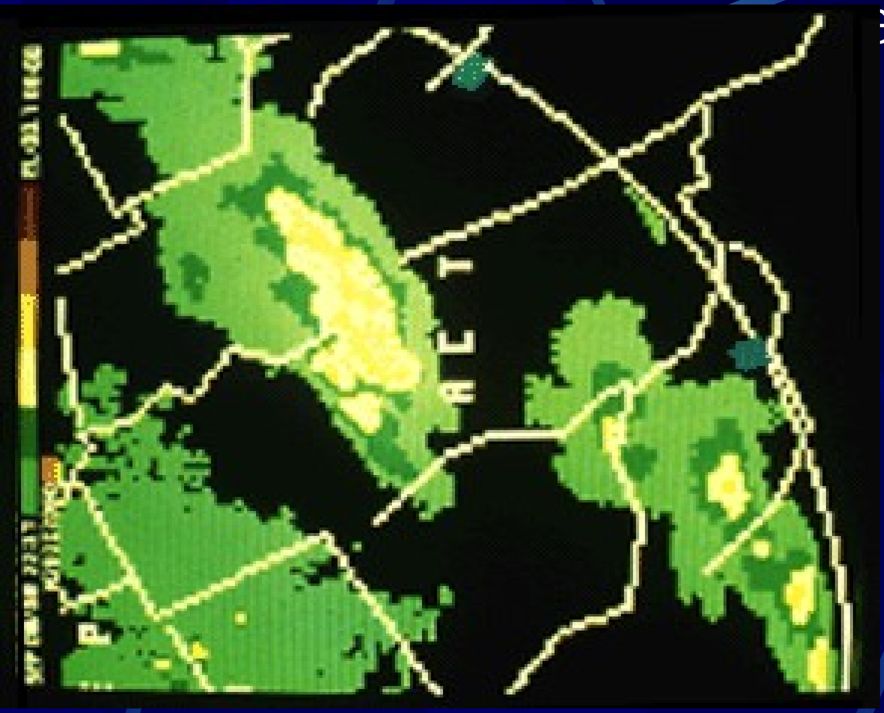
Multicell severe weather can be of any variety, and generally these storms are more potent than single cell storms, but considerably less so than supercells. Organized multicell storms have the higher severe weather potential, although unorganized multicells, wh ... es of single cells, can pro ... s of severe events.



Actually, the distinction between multicell and single cell storms is not nearly as important as that between multicells and supercells. The multicell flash flood threat can be significant, in fact most flash floods probably occur with multicell complexes. As with

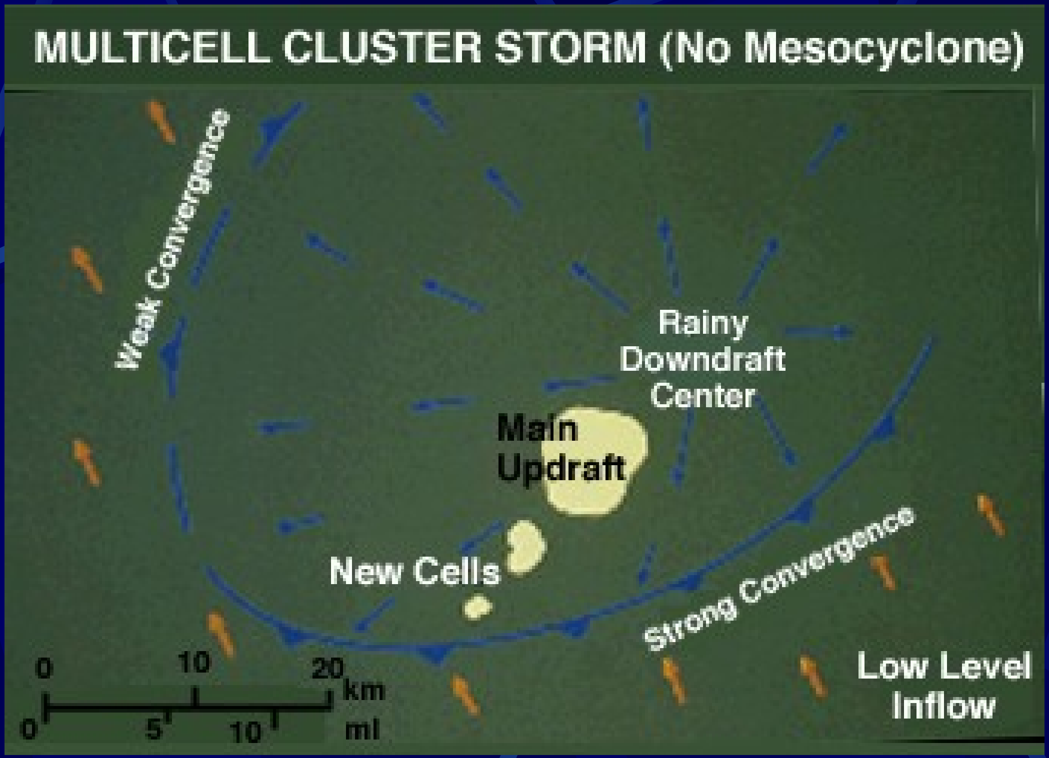
Components of Multicell Clusters

moderate dangers with some
ere risk



Radar (PPI mode) often reflects the multicell nature of these storms, as seen with the central echo mass and its three light red (in this case VIP 5) cores in this photo. Occasionally, a multicell storm will appear unicellular in a low-level radar scan, but will display several distinct tops when a tilt sequence is used to view the storm in its upper extremities

The close proximity of updrafts within the multicell cluster storm results in updraft competition for the warm, moist low-level air. Thus, updrafts never attain extremely strong vertical velocities and each has a short life span when compared to a supercell updraft. Naturally, multicell severe weather usually is less intense than that from supercells, but still can be quite potent,



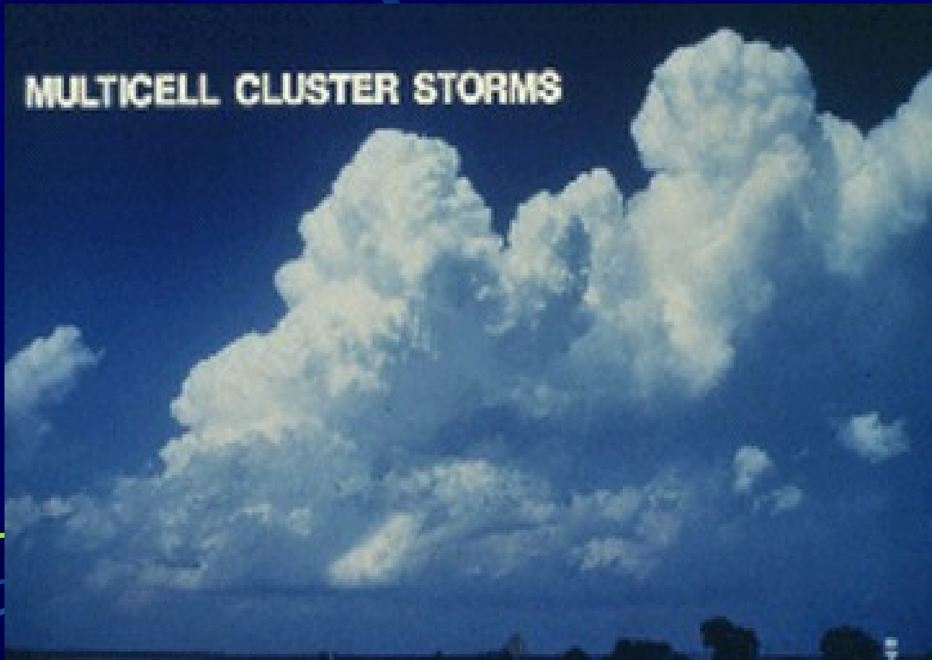
This low-level, horizontal cross-section depicts a severe multicell storm or marginal supercell where the gust front typically has moved out ahead of and "undercut" the updraft area and possible wall cloud. Although the storm might well be severe, tornado production from the updraft/wall cloud area is unlikely.

Development of Multicell Cluster Storms

the flanking line and varying sheared environments

A multicell cluster storm, the most common of the four basic storm types, evolves as an organized sequence of cells in various stages of development and decay at any given time. When multicell storms form in environments with winds which veer from southerly to westerly and increase with height, new updraft development usually occurs in the upwind (usually southwest) quadrant of the complex, with older cells decaying in the downwind quadrant.

The new development, called the flanking line, is at the left (southwest) side of the complex. The rain-free base disappears beneath the twin towers on the right-hand side of the photo, since precipitation is falling from these glaciated thunderstorm



Glaciation refers to the transformation of cloud particles from water droplets to ice crystals. The visual cloud appearance often changes from rock-hard to soft during the glaciation process. The northeastward tilt of the multicell complex above indicates the presence of vertical wind shear (looking north from about 12 miles).

Another multicell storm, this time looking south in an even more strongly sheared wind field. Precipitation is beginning to fall from the Cb top on the left (east) side of the complex. (Western Oklahoma storm, June 1980).

Multicell Clusters from Different Perspecti

viewing from the northeast and southeast

We are looking northeast from about 15 miles, along the axis of the flanking line into this multicell storm. Note the several "humps" of multicellular Cb top embedded in the anvil.

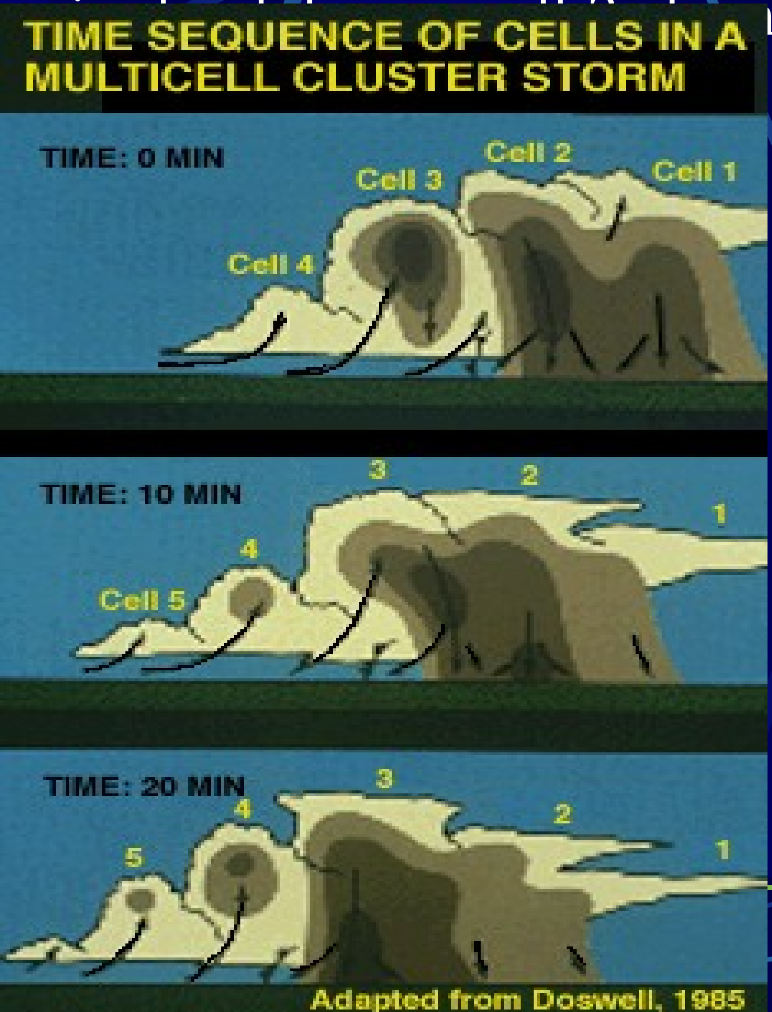
The soft or glaciated appearance of the Cb tops and anvil suggests little chance for updraft-dependent severe weather with this storm, as these visual clues strongly suggest a relatively weak or diminishing updraft.

This southeast view of another multicell storm, from about 12 miles, shows a much crisper appearing Cb top, with hard, cumuliform structure also seen in the anvil. Another clue that this is a strong updraft is the "back-sheared" anvil, overhanging the back flank of the right-to-left moving storm complex. This storm produced marginally-severe, one inch diameter hail in West Texas

Life Cycle

evolution of cells in a multicell cluster

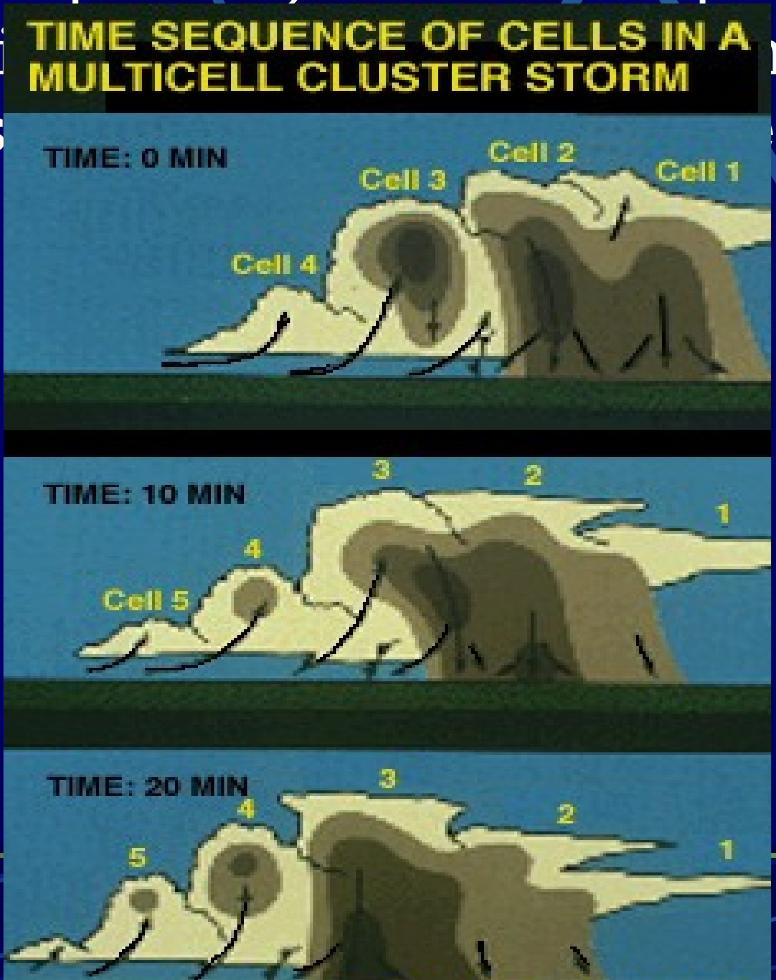
This illustration portrays a portion of the life cycle of a multicell storm. As cell 1 dissipates at time = 0, cell 2 matures and becomes briefly dominant. Cell 2 drops its heaviest precipitation about 10 ... gthens, and so on.



Thus, severe multicell storms characteristically produce a brief period of hail and/or downburst damage during and immediately after the strongest updraft stage. Later updraft resurgence may or may not result in further damage, leading to a spotty damage pattern.

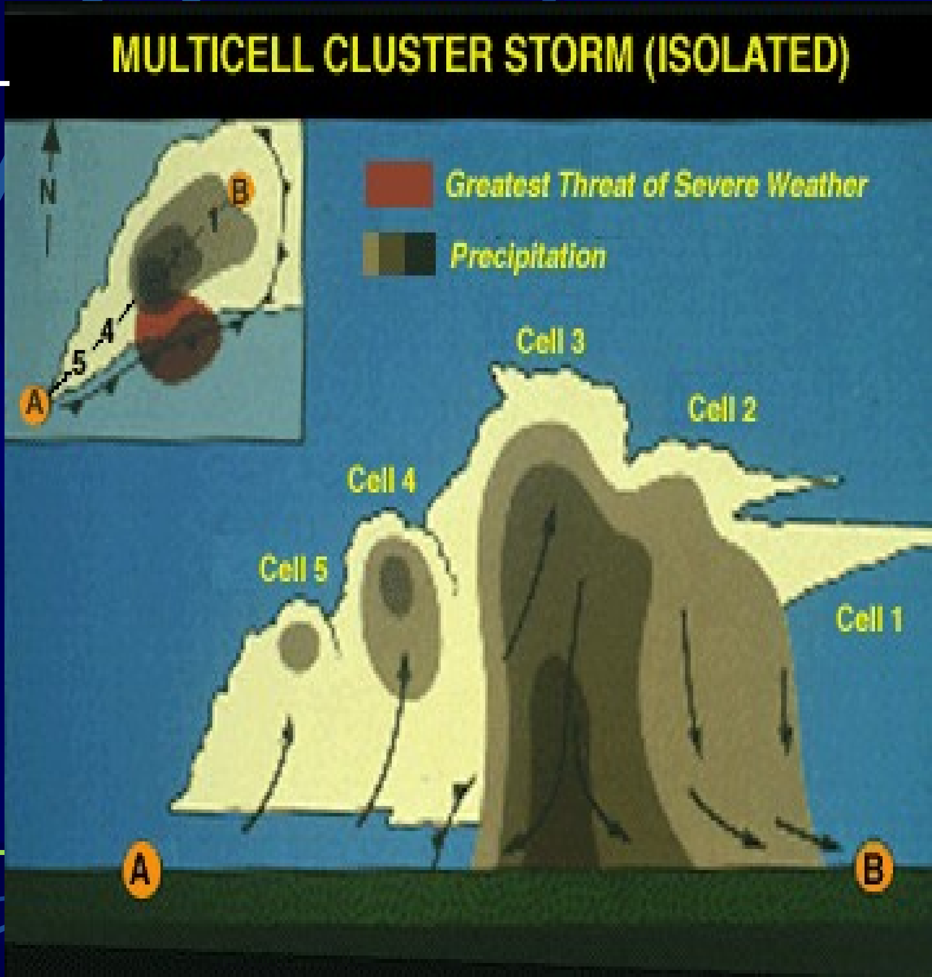
If the winds in the storm environment are blowing from left to right, it can happen that the storm motion arising from new cell development nearly cancels the motion arising from the environmental winds. Thus, new cells

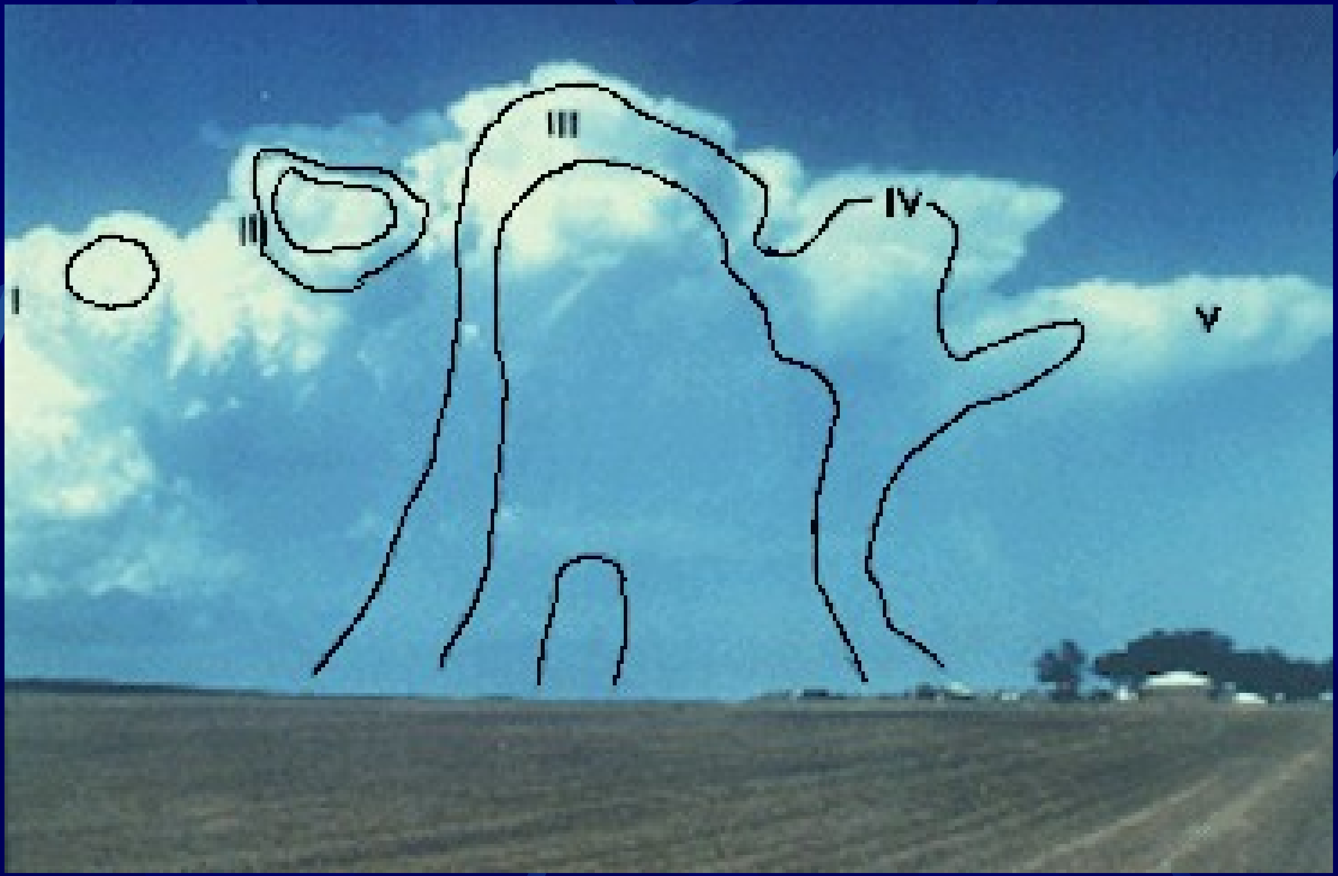
This is the train-echo pattern of flash flood producing rainfall, although train echoes also may occur as different multicell thunderstorm complexes moving across an area with a greater time interval. Not having the benefit of radar, it will seem to citizens living in an area receiving repeated, short-term precipitation bursts that the storm i … ng across again and again. This … eous notion.



A closer view at T = 20 minutes (from in the above slide) shows that cell 3 still has the highest top, but precipitation is undercutting the updraft in the lower levels. New echo development is occurring aloft in cells 4 and 5 in the flanking line, with only light rain falling from the dissipating cells 1 and 2 on the northeast side of the storm cluster.

The inset shows what the low-level PPI radar presentation might look like. This storm appears to be unicellular but the several distinct echo tops tell us otherwise. Note that the greatest risk of severe weather at this time extends from beneath the heavy precipitation areas of cell 3 (hail and downbursts) into the area of the leading gust front





Here is a real storm, with radar superimposed. Observe the physical similarities to the second slide. This Texas Panhandle storm was non-severe. Looking north-northeast from about 20 miles. Note that the updraft numbering is reversed.

Evolving Storm

an unusually severe multicell cluster storm

This is how some multicell cluster storms will appear as they approach, again assuming good visibility. The ominous shelf cloud, appearing like a mustache with this storm, is the leading edge of the storm outflow. Observe the rain-free updraft bases ahead of and above the shelf cloud. (Near Monahans, TX, 1977)

The storm was unusually severe, packing hail from 1 to 3 inches in diameter and 70 MPH winds. Most of the hail was from 1/2 to 1 inch in diameter. Looking east, note the steam fog arising he storm ends

From the backside we watch as the same storm cluster moves away to the east. Observe the southeastward-tilt of the clouds in the short flanking line and the precipitation area to the east. The flow aloft was from northwest to southeast (rather than southwest to northeast), influen

It is curious that this storm showed updrafts on the leading (east) edge as it approached, and on the back (northwest) side as it moved off. The storm was definitely multicellular, although not as "clear-cut" about preferred updraft locations as other multicell storms we have viewed. Again, nature does not always allow us to label and catalog everything neatly!

Concerning storms in northwest flow aloft, it has been observed that the updraft area frequently shifts to the southeast flank, when rain-cooled air keeps warm, southerly winds from providing a continual feed to the northwest flank updrafts. Thus, with this storm it is possible that the leading (southeast flank) updraft area became predominant once

Multicell Lines

also known as squall lines

Multicell line storms consist of a line of storms with a continuous, well developed gust front at the leading edge of the line. An approaching multicell line often appears as a dark bank of clouds covering the western horizon. The great number of closely-spaced updraft/downdraft couplets qualifies this complex as multicellular, although storm structure is quite different from that of the

Multicell line storms are better known as squall lines, which is the term that we will use from here on. The former name is for positioning squall lines in the thunderstorm spectrum.

Squall lines most frequently produce severe weather near the updraft/downdraft interface at the storm's leading edge. Downburst winds are the main threat, although hail as large as golf balls and gustnadoes can occur. Flash floods occasionally occur when the squall line decelerates or even becomes stationary, with thunderstorms moving parallel to the line and repeatedly across the same area.

MULTICELL LINE STORM

- Severe weather occurs as downbursts....small to moderate size hail...occasional flash floods.... and weak tornadoes
- Severe events most frequently occur near the updraft/downdraft interface on the leading (east) storm quadrant, especially cells associated with breaks in the line
- Moderate degree of predictability of severe events
- Moderate danger to public; Moderate to high danger to aviation

Squall lines with a confirmed severe weather history allow for the issuance of reliable warnings. Pilots should be extremely cautious, as they should for all thunderstorms, particularly near the squall line's leading updraft/downdraft

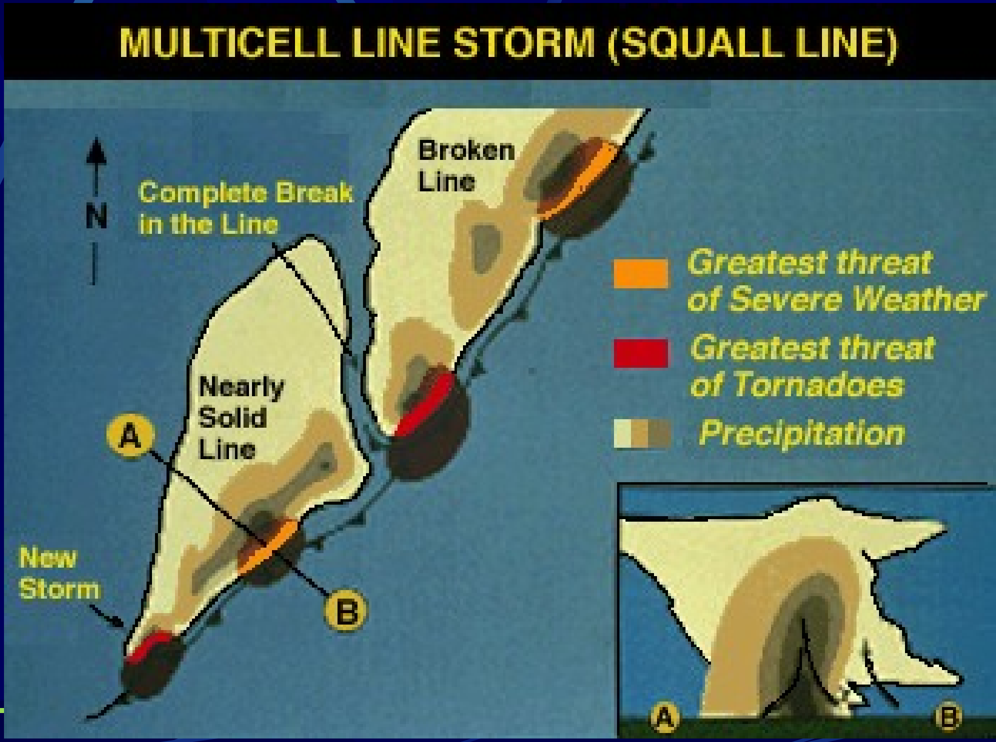
Components of multicell lines

This particular storm evolved from a supercell into a short line of storms at the time of the photograph. We are looking west from about 5 miles, as the storm approached. Wind damage and large amounts of small h squall line at this time.

The squall line is a solid or broken line of thunderstorms with a continuous, well-developed gust front on the leading edge. Thus, updrafts and new updraft development occur on the the downwind (east) side, where the squall line is moving into unstable inflow air. The gust front lifts warm moist air into the updraft, and the cool downdraft lowers mid-level air to the ground. Squall lines are common, especially in vertically

The most common severe weather element in squall lines, by far, is the downburst, with damaging winds possible from the time of gust front passage, into the period of heavy precipitation. Hail may occur with the rain, with the heaviest rain and largest hail adjacent to the updraft. Dissipating elements at the rear of the squall line often result in a period of light rain before cessation of precipitation.

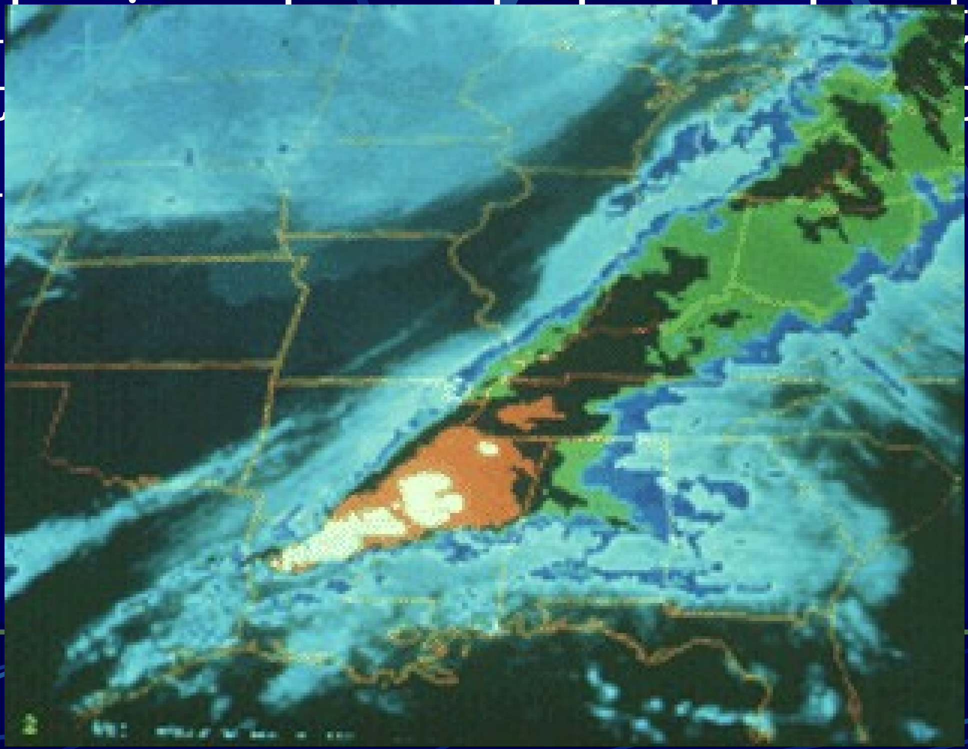
Intense storms, in rare cases even tornadic supercells, periodically occur in squall lines. The most likely locations for these more powerful storms are at an eastward bend, on the south end, or north of a significant break in the line. Note that all of these positions



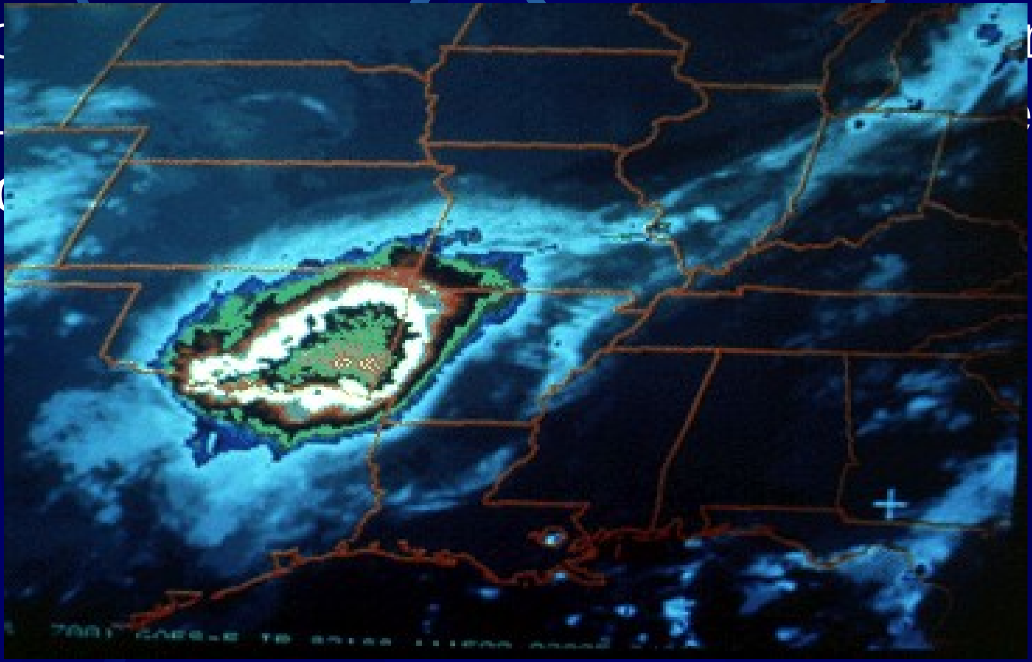
On Satellite Images

squall lines and mesoscale convective systems

This infrared satellite view of an eastward moving squall line, extending from the Ohio River Valley southwestward into Louisiana, shows the extreme lengths that thunderstorm lines can achieve. The lower, warmer anvils on the north end of the line and the colder, higher cloud tops at the south end reveal the tendency for older, weal the north side of the line wit oment near the south end



The second satellite photo shows a huge anvil cloud arising from a large cluster of storms. This is called a mesoscale convective system or "MCS". An entire MCS cannot be viewed from the ground and in some cases not even by a single radar, so we use the satellite perspective. It is a group of multicell storms, often dominated by a vigo nd (east) side and a nu r storms in the interio



An MCS often will bring severe weather and heavy rain with the squall line, and additional heavy rainfall with the interior storms. A number of major flash floods have resulted from MCS passage, making this large storm complex an extremely

Features Along The Leading Edge

shelf clouds and vaulted cloud structures

This rather innocuous appearing squall line probably is more typical in appearance than some of the spectacular squall lines we have been viewing. Note the subtle shelf cloud ahead of the dark precipitation area. This was a non-severe squall line in easte

looking west from about 5 miles

Underneath the shelf cloud and looking north, note the change in appearance from the ragged, outflow-torn clouds to the smoother elements ahead of the line. The outflow winds had commenced at this time, and hail and heavy rain were to arrive in minutes.

This strong gust front (shown below) was accompanied by 40 and 50 MPH winds and a shelf cloud with a highly-sloped

Near the light area on the southwest horizon, a downburst was resulting in damage at this time, as reported by Amateur Radio Spotters southwest of Fort Worth, Texas. The squall line

an examination of backside features

After the precipitation has ended, a squall line is seen moving into the eastern horizon. Stable, stratiform clouds (those that develop in layers rather than clumps) predominate on the rear flank of a squall line.

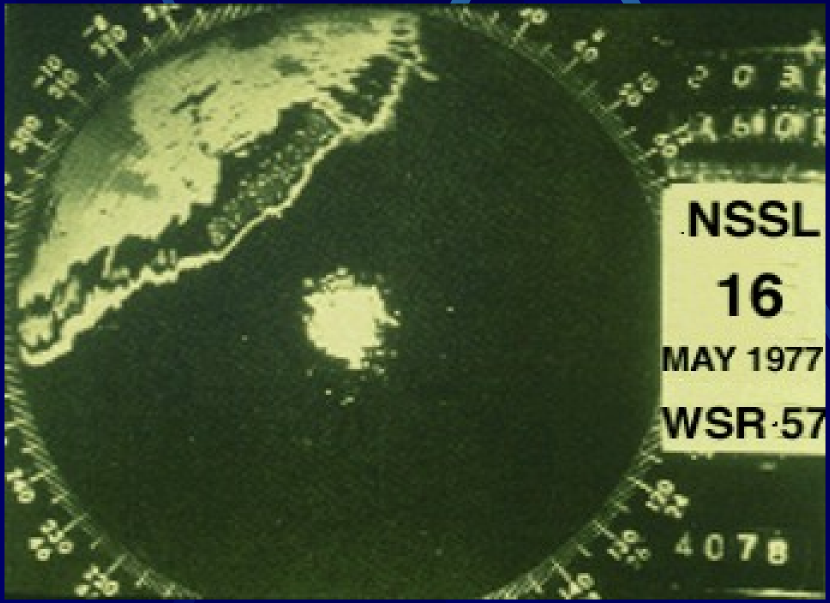
Mammatus often appear on the underside of the rear flank anvil (although they are also common on the front-flank anvil), as in the upper portions of the photograph. This upwind squall line anvil is not the same as a strongly back-sheared anvil, but consists of anvil refuse left behind as the advancing gust front moves rapidly eastward. The same phenomenon occurs when the squall

Continuing its eastward movement, a squall line is pictured at sunset, looking to the distant southeast. The largest tops near the south end of the line graphically illustrate the tendency for fresh, strong convection to build southward with time, towards the area of strong inflow.

Linear Radar Echoes

squall lines on radar images

Radar indicates the linear nature of a squall line. The strongest radar reflectivity (VIP) levels on the leading edge reveal the locations of updrafts and adjacent regions of heavy precipitation.



From the eastern plains of Colorado we see a distant, approaching squall line, about 20 miles to the west. Further east from the High Plains, we would be less likely to have this unrestricted view because of haze and intervening clouds.

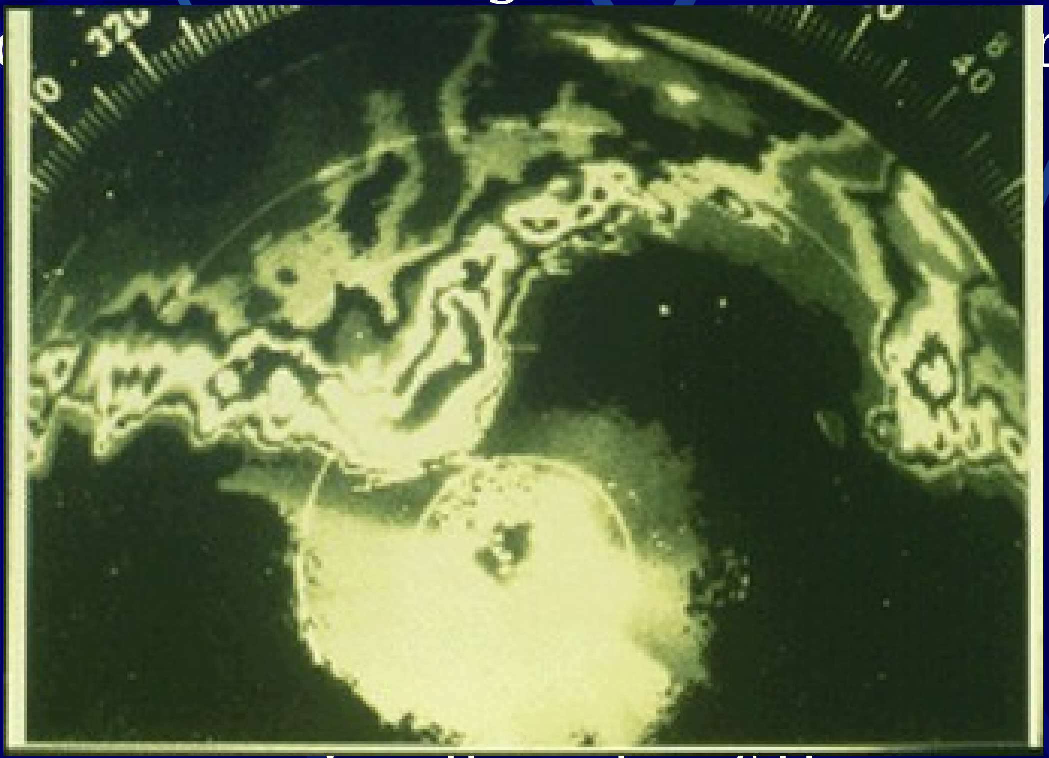
Nevertheless, similar storm structure, with new updrafts developing on the leading edge of the gust front, will be present regardless of location.

Bow Echoes on Radar

often accompanied by strong outflow winds

Large scale bow-shape squall lines sometimes are called line-echo wave patterns (LEWPs). Large areas of strong outflow winds, sometimes reaching strong downburst force, often occur. Tornadoes have been known to occur near and north of the apex of the bow. Widespread but scattered minor wind damage occurred along the eastward bow of this

Below is a smaller scale bow echo. Short thunderstorm lines and multicell cluster storms can both evolve into bow echoes. Research indicates that these smaller scale bow echoes can be more dangerous than the large scale variety, with r more likely to develop.

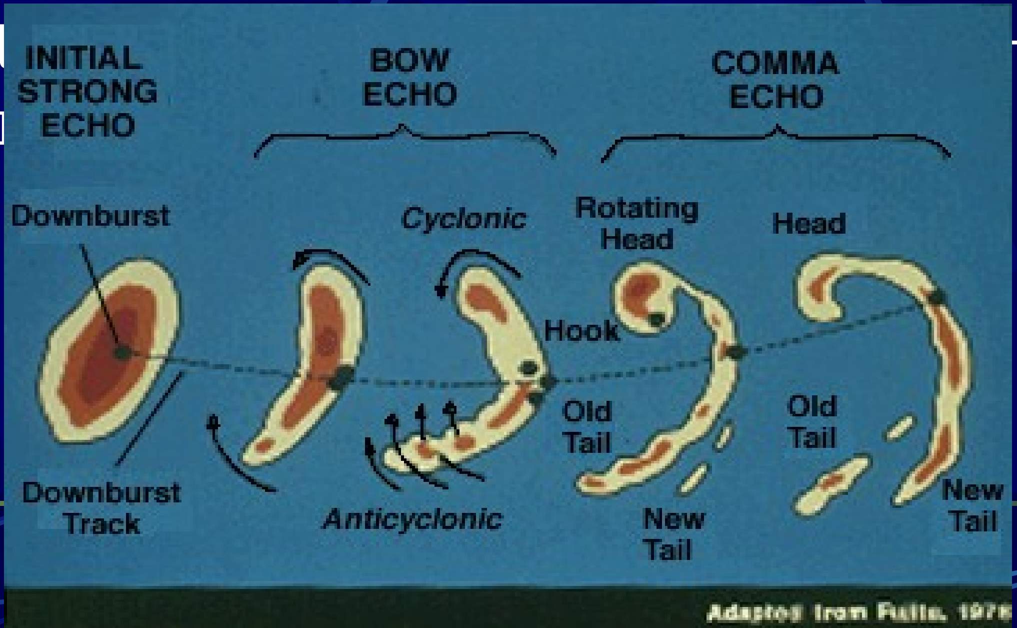


Bow echo storms occur in all parts of the country during unstable periods and with fairly strong vertical wind shear, but they seem to have a particular affinity for the area from the Northern and Central Plains eastward into the Ohio River Valley during strong

More About Bow Echoes

schematic radar view and observed events

Squall lines and multicell storms occasionally develop the appearance of a "bow echo" on radar. When the bow shape opens toward the strong mid-level winds (10 to 20 thousand foot level winds of 40 knots or greater), there is an excellent chance that the strong mid-level currents have been transported to the ground in a downburst, forcing a portion of the squall line or multicell storm to accelerate forward. Macroburst and microburst winds are common wit H winds have been repor



Weak to occasionally strong tornadoes may occur with the comma head, while gustnadoes may form on the strong bow echo gust front.

This is a northward view of a gustnado, a tornado that develops on a thunderstorm gust front with marked across-front horizontal shear. Gustnadoes typically are weak and short-lived as tornadoes go, since they are not associated with an intense deeply rotating updraft. They are also nearly impossible to warn for, because of their seemingly random occurrence along the gust front.

The bow echo weakens as the accelerating downburst outruns the storm complex. Those who operate radar should be aware that the rotating comma head occasionally has deceptively weak radar reflectivity while producing damaging winds and tornadoes.

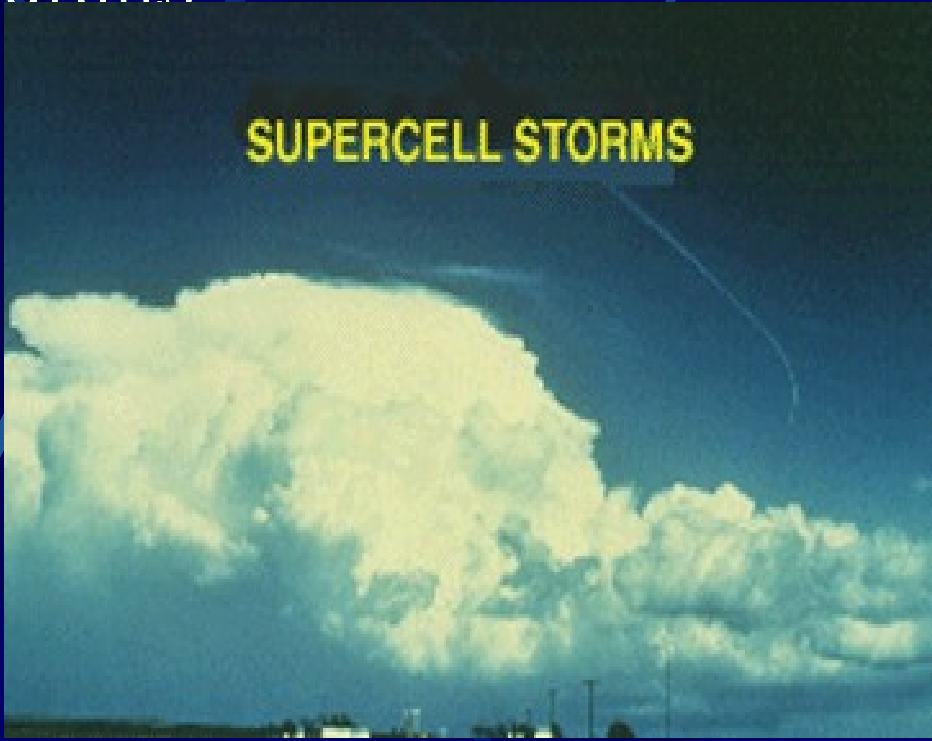
Smaller scale bow echoes frequently can be detected from visual observations. This southward view shows the underside of a right to left (eastward) moving storm's shelf cloud, with the southern extent of the complex bowing radically eastward in the background. Damaging winds and a radar bow echo occurred within this area.

We need to stress that it is not the job of spotters to detect and report bow echoes, but spotters should know what they are dealing with and what the main severe weather threats are if Weather Service personnel ask

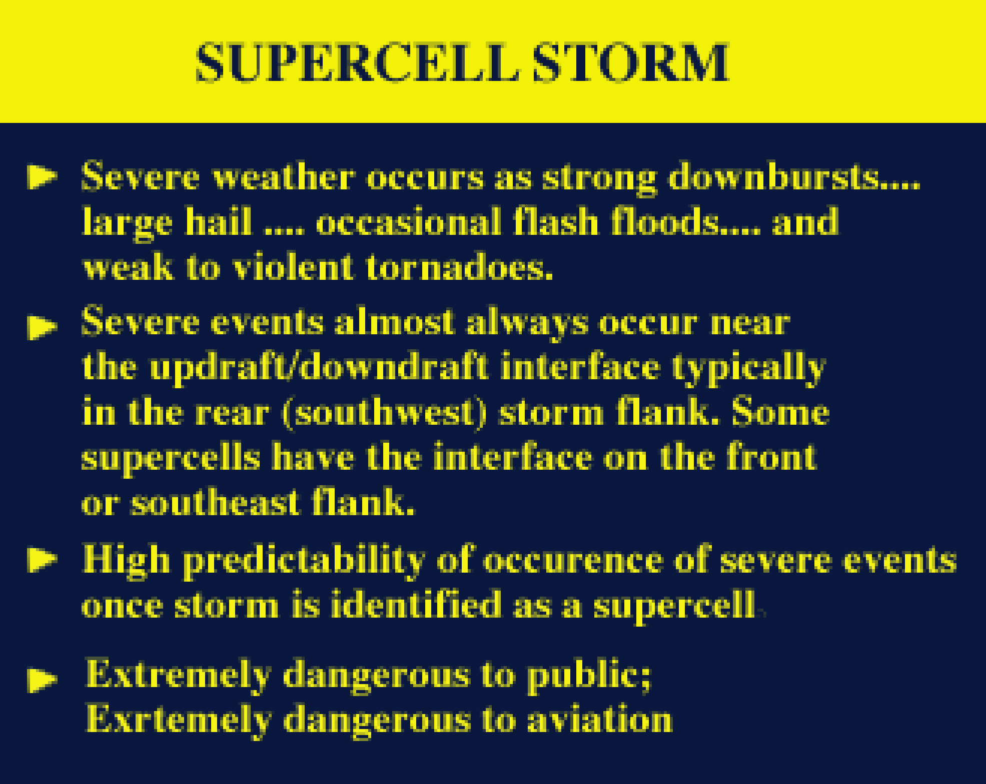
Supercell Thunderstorms

thunderstorms with deep rotating updrafts

The last of the four major storm types is the supercell. We define a supercell as a thunderstorm with a deep rotating updraft (mesocyclone). In fact, the major difference between supercell and multicell storms is the element of rotation in supercells. As we shall see, circumstances keep some supercells from producing tornadoes, even with the presence of a mesocyclone.



Even though it is the rarest of storm types, the supercell is the most dangerous because of the extreme weather generated. This storm was producing baseball hail east of Carnegie, Oklahoma, as it was photographed looking east from 30 miles. From right to left (south to north), we note the flanking line,



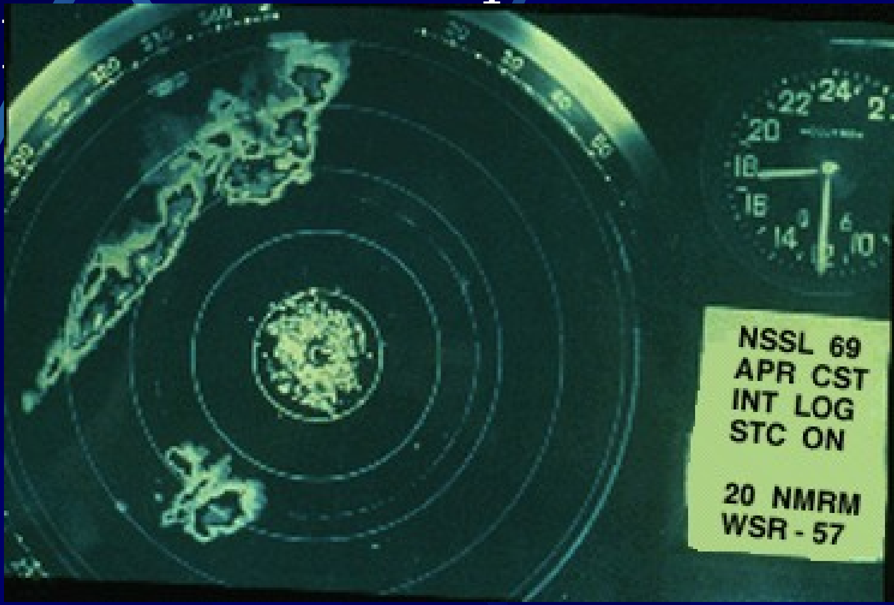
The flanking line of the supercell behaves differently than that of the multicell cluster storm, in that updraft elements usually merge into the main rotating updraft and then explode vertically, rather than develop into separate and competing thunderstorm cells. In effect, the flanking updrafts "feed" the supercell updraft, rather than compete with it.

In summary, supercells are extremely dangerous, but excellent warnings are possible once the storm has been properly identified. The demarcation between supercell and multicell storms is most important, obviously much more so than that between single cell and multicell storms, or between multicell and squall line storms. As mentioned earlier, it has been suggested that thunderstorms simply be classified as "supercells" and "ordinary" storms. A few supercells will have

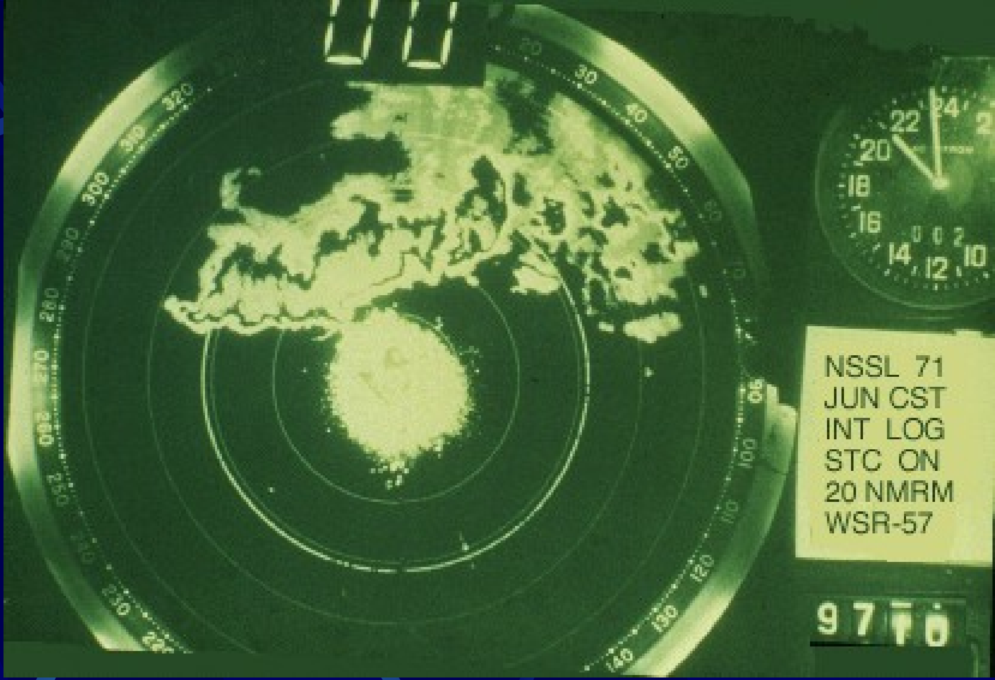
On Radar Images

supercells tend to develop in isolation

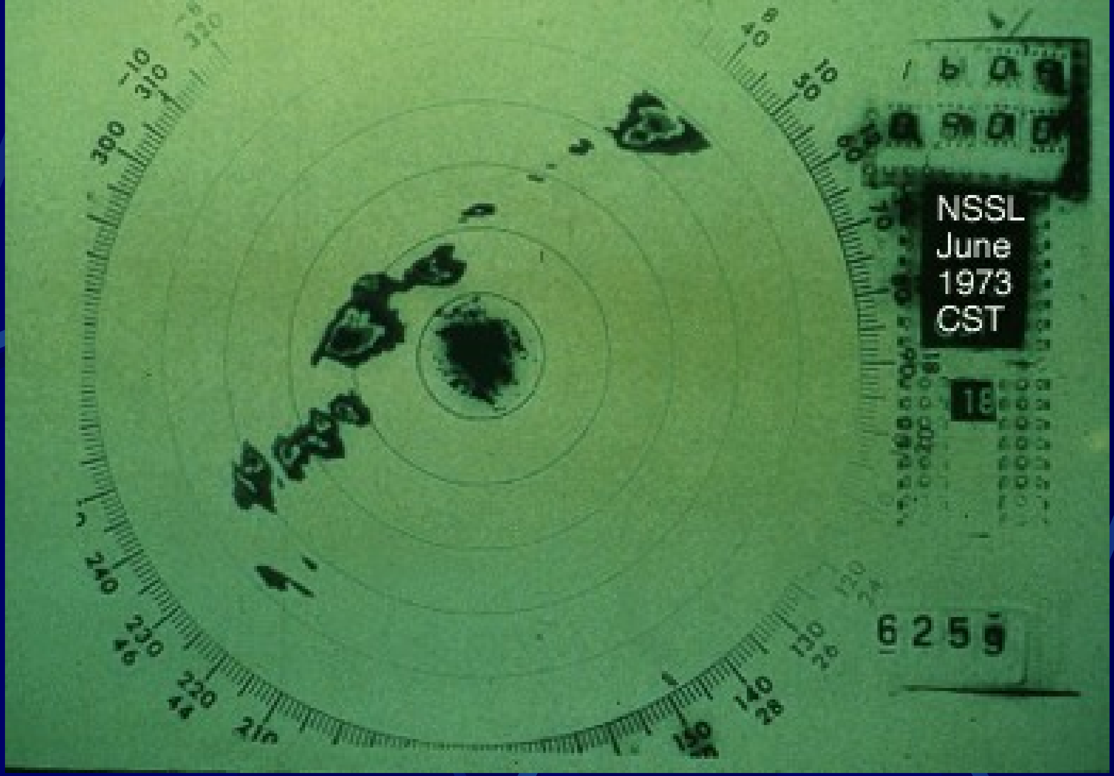
Supercells most frequently are isolated and often develop in the warm air ahead of a squall line. This supercell formed south-southwest of the radar site and produced large hail and tornadoes well al
squall line.



This supercell, north-northwest of the radar, developed within an east-west oriented solid squall line. It produced severe weather and funnel clouds, but no known tornadoes. Subjective experience suggests that such storms are not as likely to produce strong to violent tornadoes as are more isolated storms.



However, other evidence shows that storm spacing, which is necessary for significant tornado formation, is probably greater on the High Plains than that in the southeast U.S., possibly because of the abundant moisture near the Gulf of Mexico. Supercells frequently occur in "preferred" regions relative to other radar echoes. First, in this case of a scattered to broken line of thunderstorms, a supercell is evident due west of the radar site, positioned in a weakly-developed LEWP

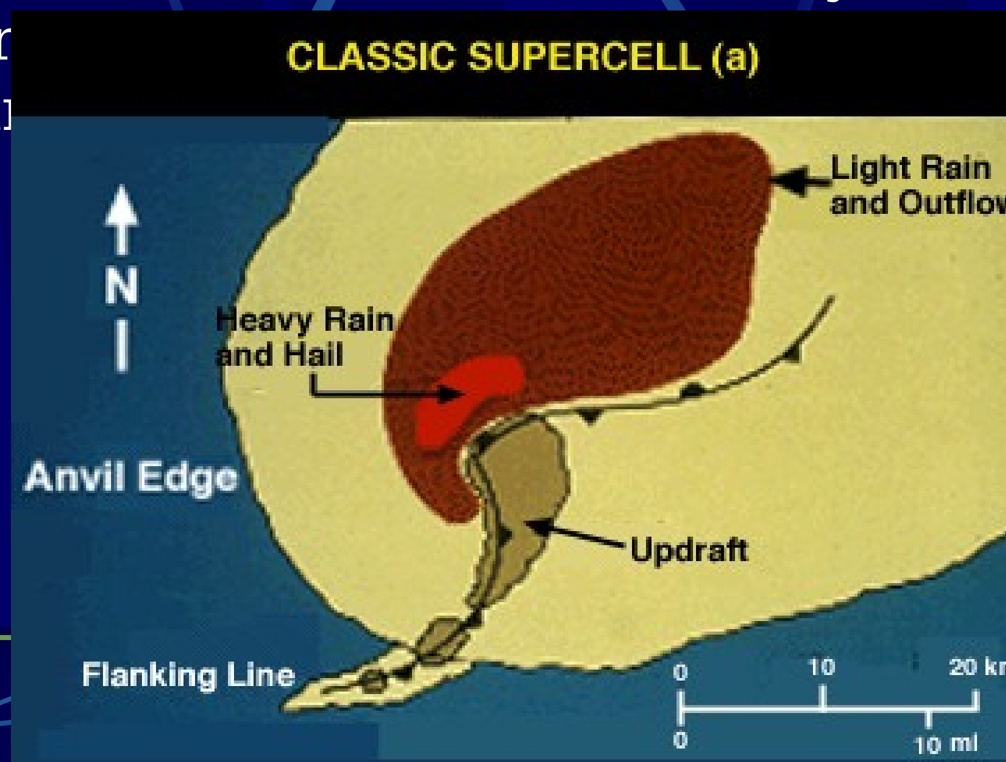


Surface data indicates that a small scale low pressure system, about 100 miles in diameter, probably accounted for the LEWP configuration. Supercells often form near or immediately northeast of such a low. The lack of other storms in the immediate vicinity of this supercell allowed the intense storm to produce tornadoes and large hail for several hours without interference. The slow-moving storm also produced flash flooding.

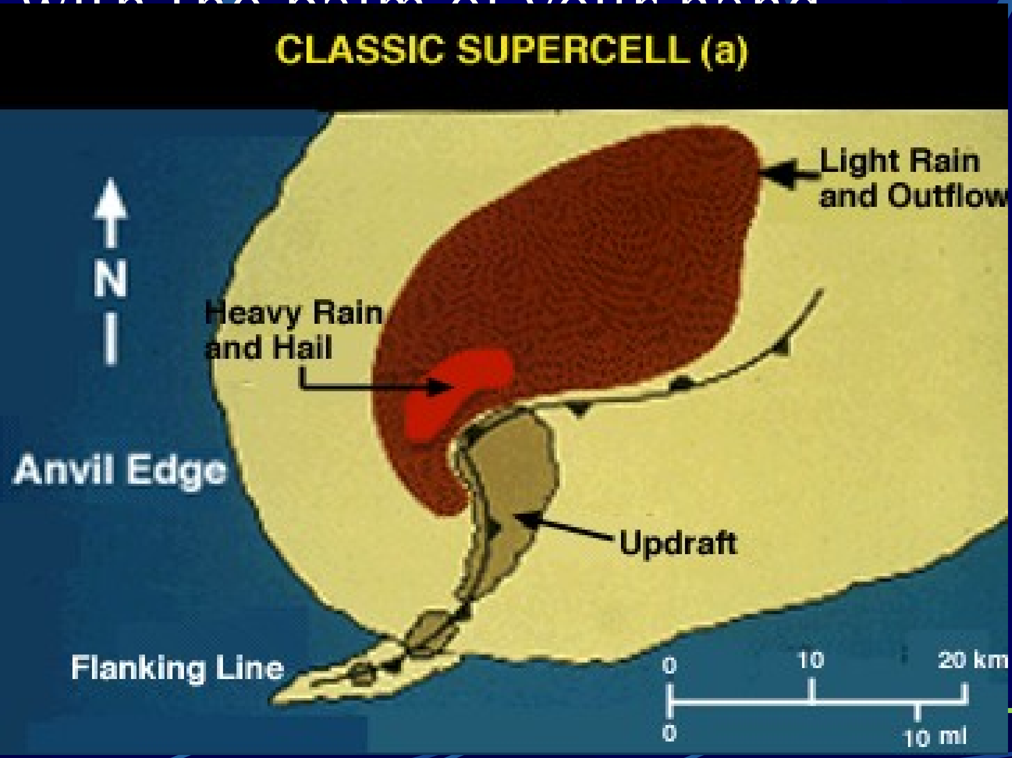
Schematic Diagrams

horizontal cross-section and westward view

This is a horizontal, low-level cross-section of a "classic" supercell. The storm is characterized by a large precipitation area on radar, and a pendant or hook-shaped echo wrapping cyclonically around the updraft area. Note the position of the updraft and the gust front wave. The intense updraft suspends precipitation particles above it, with rain and hail eventually blown off of the updraft summit and downwind by the strong winds aloft. Updraft r ave, with warm surface ai isture to the storm.

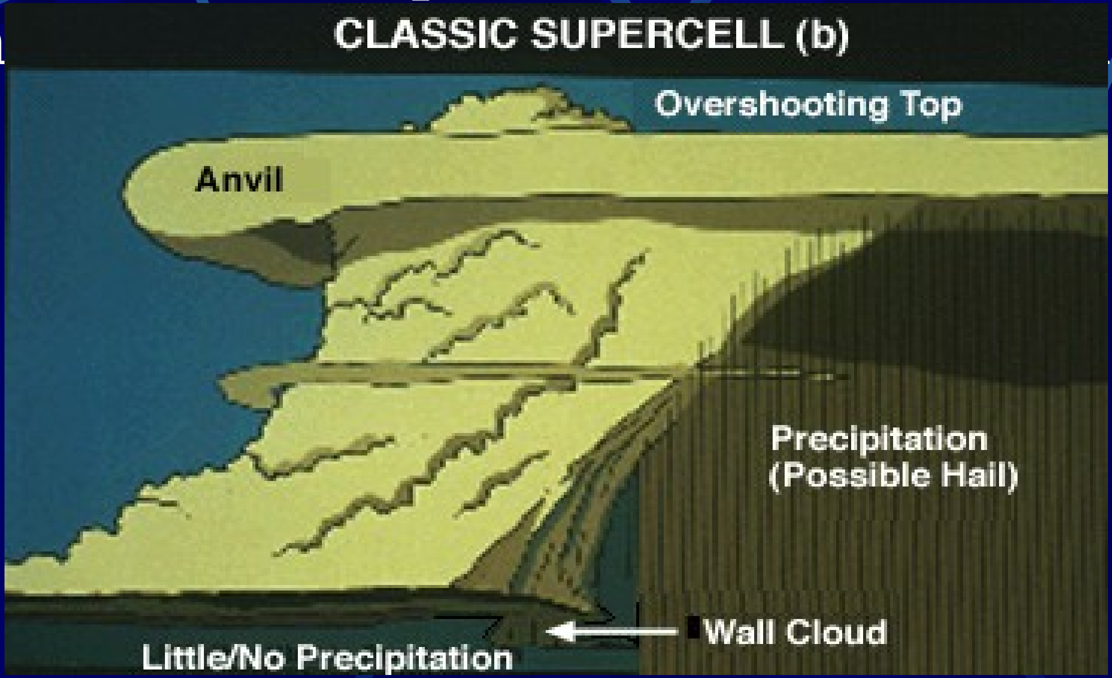


Updraft rotation occurs when winds through the troposphere are moderate to strong, and low-level turning is significant. As inflow air in the lowest 1-3 kilometers approaches the storm from the south or southwest, the low level turning results in the development of rotation about a horizontal axis. As the air is lifted into the updraft, the rotation is "tilted" to that about a vertical axis. To see this rotation about a horizontal axis caused by wind shear, imagine rolling a tube along a table-top with the palm of your hand.



The movement of your hand represents the strong winds above the surface, producing rotation because the winds near the ground are much weaker. This simple picture is complicated by the turning of the wind direction with height, but the concept remains similar. Lifting this "horizontal" vortex into the updraft results

A westward view of the classic supercell reveals the wall cloud beneath the intense updraft core and an inflow tail cloud on the rainy downdraft side of the wall cloud. Wall clouds tend to develop beneath the north side of the supercell rain … rations occur.



Observe the nearly vertical, "vaulted" appearance of the cloud boundary on the north side of the Cb and adjacent to the visible precipitation area. A sharp demarcation between downdraft and rotating updraft results in this appearance. Note the anvil overhang on the upwind (southwest) side of the storm and the overshooting top.

Overshooting Tops

indicative of powerful updrafts

Looking east from about 40 miles away, we see a line of towering cumulus clouds and a large supercell storm in the background. Note the great amount of anvil overhang and the large overshooting dome at the summit of the updraft.

Distant supercells frequently have this domed, "diffluent" anvil appearance, with the supercell's tremendous updraft velocities and outflow resulting in marked upper-level divergence. The visual clues are strong, although we cannot be sure that this is a supercell simply from appearance. By necessity, man and machine (i.e., spotters and radar) complement each other in the severe weather detection program. This storm produced

This supercell featured a rock-hard, overshooting Cb top and anvil overhang, looking southeast from about 40 miles away. Note that the supercell Cb is more vertically oriented than the weaker updraft of the neighboring towering cumulus cloud. This is a valuable clue in estimating the strength of updrafts on a day with strong vertical wind shear. This storm produced baseball hail, but no known tornadoes, along a track in southeast Oklahoma and southwest Arkansas.

Rotating Updrafts

visual clue

There are ample signatures of updraft rotation in this hazy, northeastward view of a very intense supercell from 40 miles away. The circular mid-level cloud bands and the smooth, cylindrical Cb strongly hint of updraft rotation. Above the mid-level cloud band, an extremely hard Cb top is barely visible (upper right) towering into the anvil. Note the smooth, "laminar" flanking line on the extreme left. A strong,

Cloud elements moved along the flank into the main Cb, with rapid vertical development occurring at the merger point. Close examination of the photo will reveal a wall cloud beneath the lower left edge of the Cb, with a relatively bright "clear slot" ahead of the wall cloud. Within 20 minutes, the storm

A close, westward view of a supercell updraft and adjacent precipitation cascade strikingly resembles the model we have just seen. Wall clouds frequently slope downward towards the precipitation area, as shown. If you are a mobile spotter and encounter a view such as this, turn around and out-run the storm by going eastward or, better yet, move away from the storm to the southeast. This is very close to the fall area of large hailstones, and moving north or waiting at this location

Backlighting

for better viewing of tornadoes

A view toward the west or northeast, often with revealing backlighting, typically offers the best view. This is the same Itaska, Texas storm, seen through a telephoto lens, looking west from about 15 miles!

Such spectacular distant views are relatively rare, especially in the east and southeast U.S. where low clouds, haze, precipitation, trees, and hills make spotting from a distance more difficult.

In this rare photograph we can see both the parent cumulonimbus cloud (Cb) and the tornado.

The indentation on the left side of the Cb in this photo seems to verify the presence of a rear flank downdraft (RFD), with a clear distinction between hard-textured updraft cloud and the ragged, dissipating cloud elements caught in the RFD. The tornado is at the intersecting point of the rotating updraft and RFD.

Variations

supercell storms come in a variety of shapes and sizes

Supercell storms come in different shapes and sizes, as observed on radar and by the human eye. Some are very prolific precipitation producers, whereas others produce very little precipitation that reaches the ground.

This is a westward view of a high precipitation (HP) supercell approaching in the evening light.

Hard, cumuliform anvil overhang, a vertical Cb edge, and flanking line are all visible in this southeastward view of a supercell storm. Mammatus can be seen on the underside of the north Texas supercell. Golf ball size hail, downbursts, flash flooding, and rotating wall clouds occurred without any known tornadoes

This slide shows the problem that frequently arises in viewing a tornadic storm to the north -- lack of contrast. The dark precipitation area all too often blends in with wall clouds, tornadoes, etc. However, important clues as to the nature of this particular storm are visible, including the circular, mid-level cloud bands we saw in an earlier storm. These bands suggest rotation, and this storm did produce at least one tornado.

Also note the flat, elongated cloud on the right side of this photo. This is another type of "tail cloud," with the appearance of a beaver's tail. The east-west oriented cloud frequently is seen in the vicinity of the stationary gust front or "pseudo-warm front," which is northeast of the rotating updraft. The "beaver's tail" usually is at rain-free base level, slightly higher than the tail cloud associated with a wall cloud. Storm chase veterans consider these clues to be strong evidence of a supercell and suggestive of possible tornado formation, although

High Precipitation (HP) Supercell

very heavy rainfall, possible large hail, downbursts and tornadoes

In this photograph, the typical HP storm visual appearance is present: beaver's tail inflow bands curling into the front-flank updraft, a gray area of anvil precipitation to the north, and a dark rain and hail core to the southwest, falling from what earlier had been the rain-free ba

In the HP stage, this storm produced large hail, gusty winds, and extremely heavy rainfall, as well as several funnel clouds. One of these is visible where the inflow bands intersect the updraft. Continuous lightning occurred with this storm, much of it in-cloud, but a sizable percentage being cloud-to-ground strikes. Indeed, HP supercells seem to be especially prolific producers of lightning.

Another HP supercell is pictured in the distant west. The characteristic inflow bands are present in front of a translucent, anvil-born precipitation area on the extreme right. Note the rotating, vaulted Cb adjacent to the anvil precipitation, and the dark precipitation shaft in the left-center, emanating from an area that would be visually rain-free in a classic supercell. This storm produced a 1/2 mile wide tornado shortly before this time. It later produced several smaller and weaker tornadoes. Many times

Characteristics of (HP) Supercells

radar features, weather events and severe events

Heavy precipitation supercells have some identifiable radar features, including "broad hooks" and/or large inflow notches on the east and southeast storm flank. A lemon technique tilt sequence will indicate a weak echo region (WER), overhang, and highest top in alignment on the leading flank. These storms will be quite difficult for spotters to handle because of both the lack of contrast between the updraft and surrounding rainy downdraft areas, and lack of past trai

HP supercells are prolific flash flood producers, and this threat should not be overlooked in light of the other severe weather elements being reported with such a storm


HIGH PRECIPITATION SUPERCELL

- HP storms have some "classic" radar signatures and few detectable classic visual signatures
- Weather events can include:

  Large hail
  Weak tornadoes
  (on rare occasions strong or violent tornadoes)
  Strong downbursts
  Torrential flash flood rainfall

- Severe events typically occur on the front (southeast) storm flank

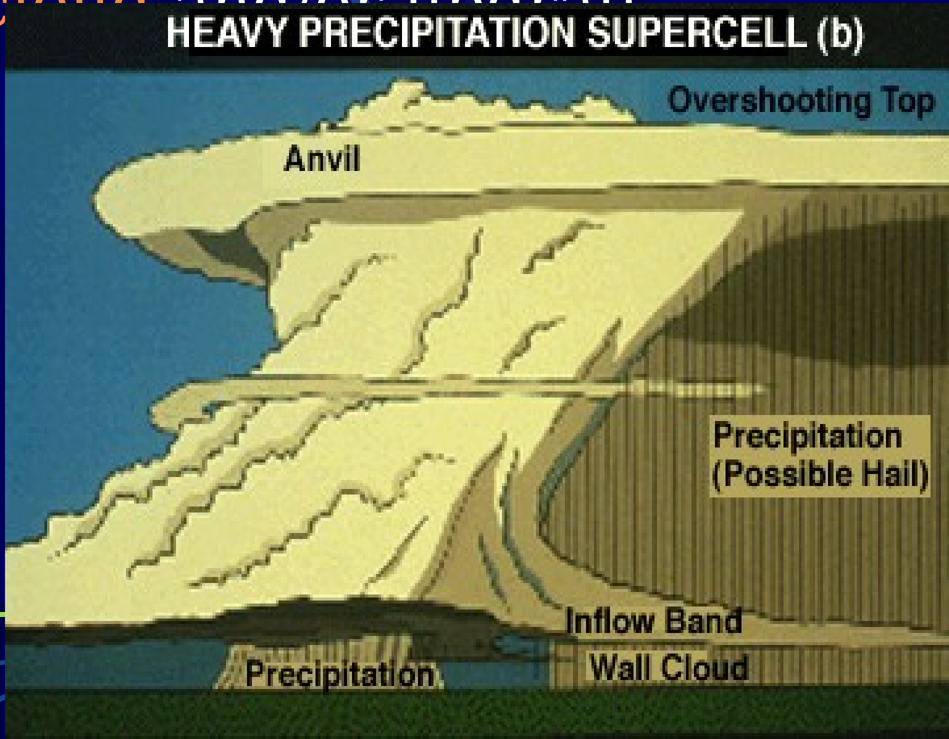
An HP storm in Fort Worth, Texas, produced almost 5 inches of rain within one hour, with most of the rain falling within 45 minutes. Some indications are that HP storms might be somewhat more frequent in the southeast U.S., but they do occur in most areas east of the Rockies. Quite important to storm spotters and severe weather forecasters is that HP supercells probably account for many of the "tornado embedded in rain" events, a ... y in the southeast but ... ains.

Westward View of HP Supercell

precipitation curtain wraps around the west and southwest flanks

A westward view of a composite HP storm model shows the position of an inflow cloud band, very similar to the previously mentioned beaver's tail cloud in the classic supercell. In fact, the HP storm has an appearance similar to the classic supercell, except for the opaque precipitation curtain wrapping around the west and southwest flanks of the wall cloud and/or updraft.

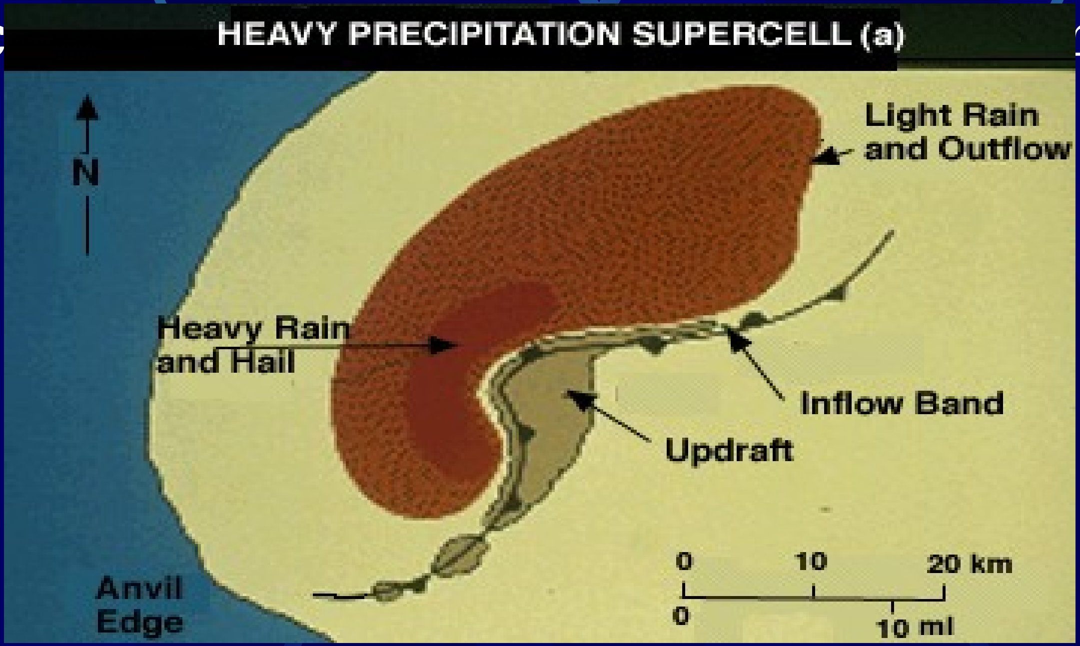
Sometimes the precipitation is a solid visual curtain, and at other times there is a distinct break, shown here, between the precipitation falling from the anvil area and that descending from the southwest flank. The southwest flank precipitation shaft is often visually dark and blue-green in



This is a westward view of an HP storm in extreme northeast Colorado. Cyclonically-curving inflow bands are visible in the upper portions of the photo, feeding into the updraft area. The storm had a very well-developed wall cloud, with precipitation wrapping around the north, west, and southwest flanks of the lowered cloud base. Note the subtle gust front and shelf cloud extending southward from the wall cloud.

Spotters will have a difficult time with the HP supercell, since there can be poor visual contrast between the wall cloud and precipitation behind it. The strongest visual clues in identifying this type of supercell usually are the curving inflow bands and mid-level cloud bands which wrap around the updraft, both

This is a low-level, horizontal cross section through a wet or heavy precipitation (HP) supercell. Basically, the HP supercell has a broad hook or pendant, usually with high radar reflectivities (VIP 5s or 6s). Occasionally, the HP supercell has an even more pronounced southwest flank precipitation area, with the radar ec n or letter "C".

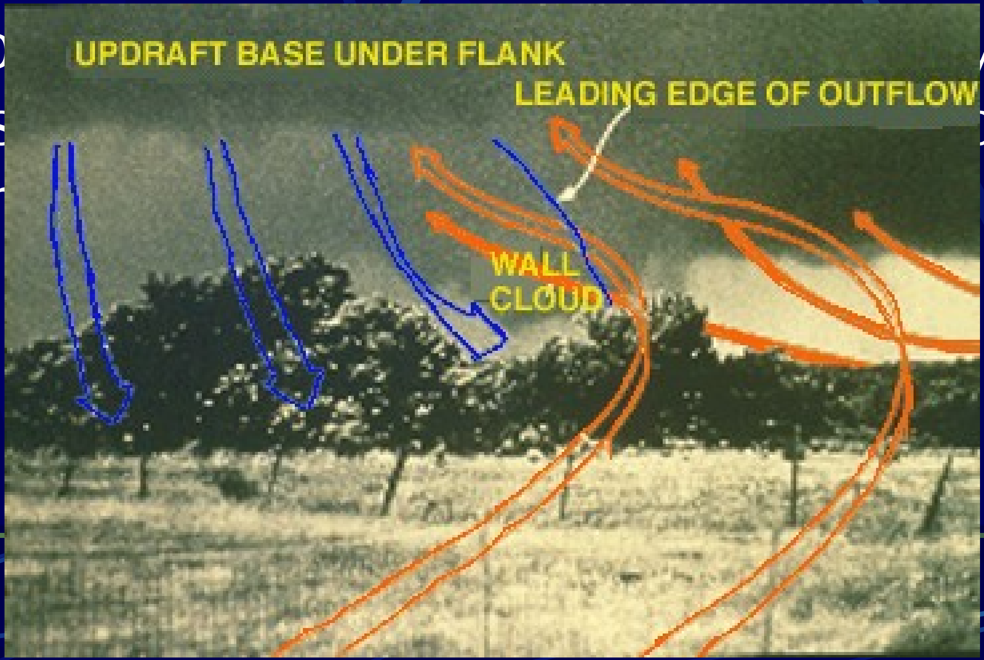


The inflow/rotating updraft notch will face east, and with nearly equal size precipitation areas northwest and southwest of the mesocyclone. Whichever is the case, the rotating updraft is on the leading storm flank, with heavy precipitation falling into the west and southwest flanks of the mesocyclone. Note the inflow band in the vicinity of the pseudo-warm front

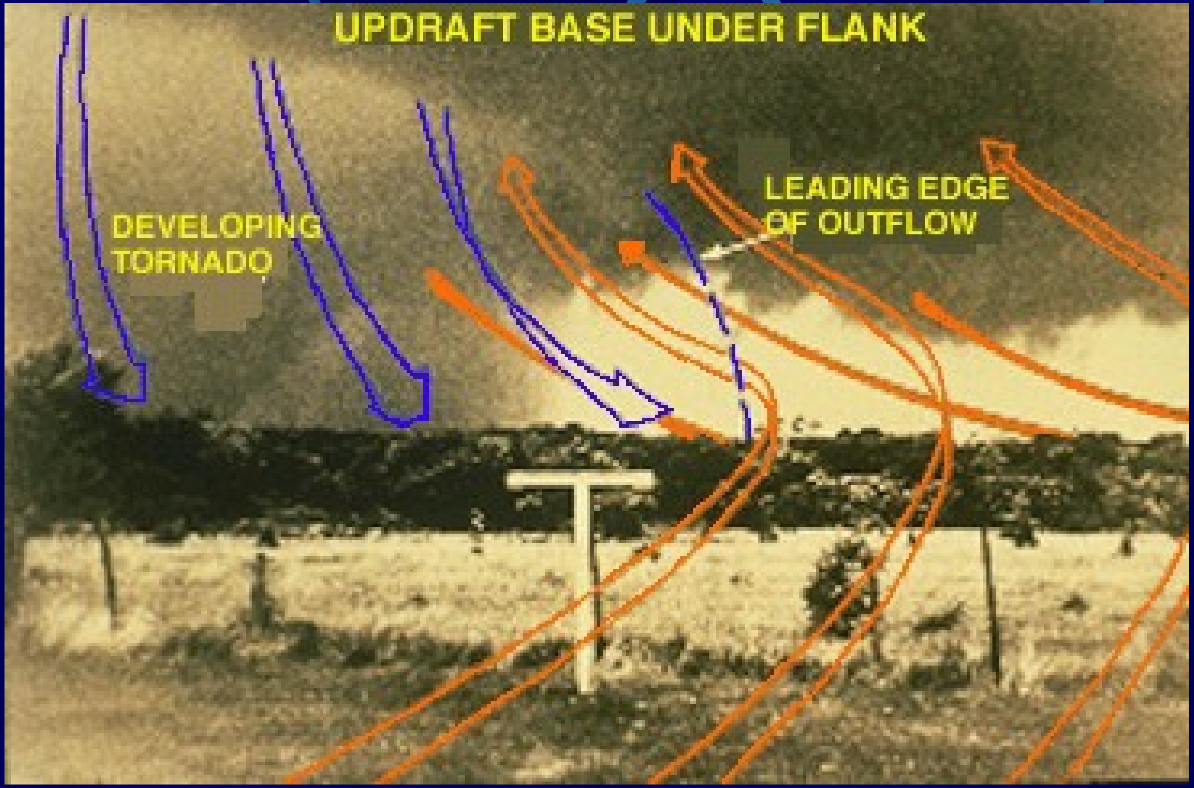
Flow Field of Tornadic HP Supercells

inflow and outflow

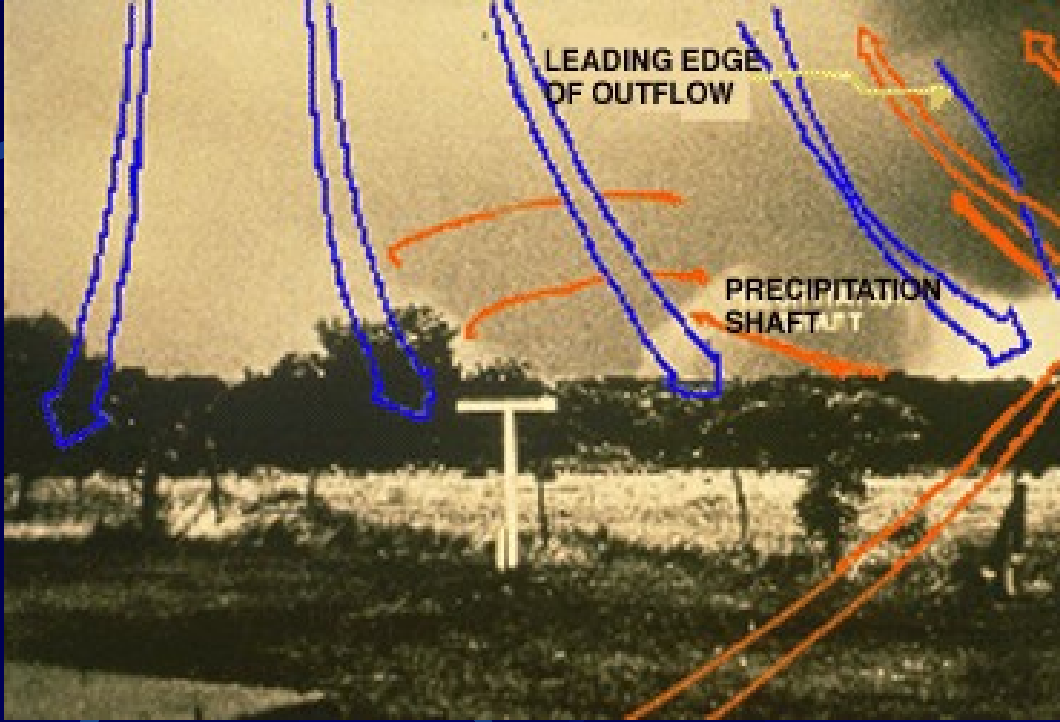
A few HP storms do produce violent tornadoes. When they occur, the tornadoes often will be wrapped in precipitation and quite difficult to observe. The photographer heard a roaring sound, and ran outside where he had this westward view. Behind the super-imposed inflow arrows is a wall cloud, with a rain area and RFD wrapping from left to right around the wall cloud's southeast flank. This rain shaft is visual manifestation o "fat" radar hook in this cas cloud and developing torn



We are in a position of strong inflow, as noted by the northward-bending trees (in the image below). However, a gust front (blue, descending arrows) is accompanying the precipitation and approaching the photographic position. The brunt of the HP storm's precipitation area is out of the photo and to the right (northeast of the wall cloud).



Still hearing a roaring sound, the photographer shifted his view a bit towards the northwest. Almost hidden behind the advancing rotating rain curtain is a large and devastating tornado!



The rain curtains that wrap around an HP supercell's tornado often change very quickly in appearance. Minutes later, the tornado is not quite as obscured by the precipitation. View these three slides a second time and observe the advance of the rain curtain and gust front. The tornado was continuing to receive a narrow corridor of inflow from the northeast at this time, as it

Developing Along Outflow Boundaries

from previous thunderstorms

HP supercells frequently have been observed to develop or intensify as they moved parallel to and along a stationary outflow boundary from previous thunderstorms. This is a northward view of such an outflow boundary, with several large thunderstorms in the distant and extreme right side of the photo moving away from ou ... loud that has been left l ... e boundary.

Looking southwest along the same outflow boundary, observe the distant thunderstorm at the end of the outflow line, with the Cb tower and anvil visible on the left hand side of the photo.

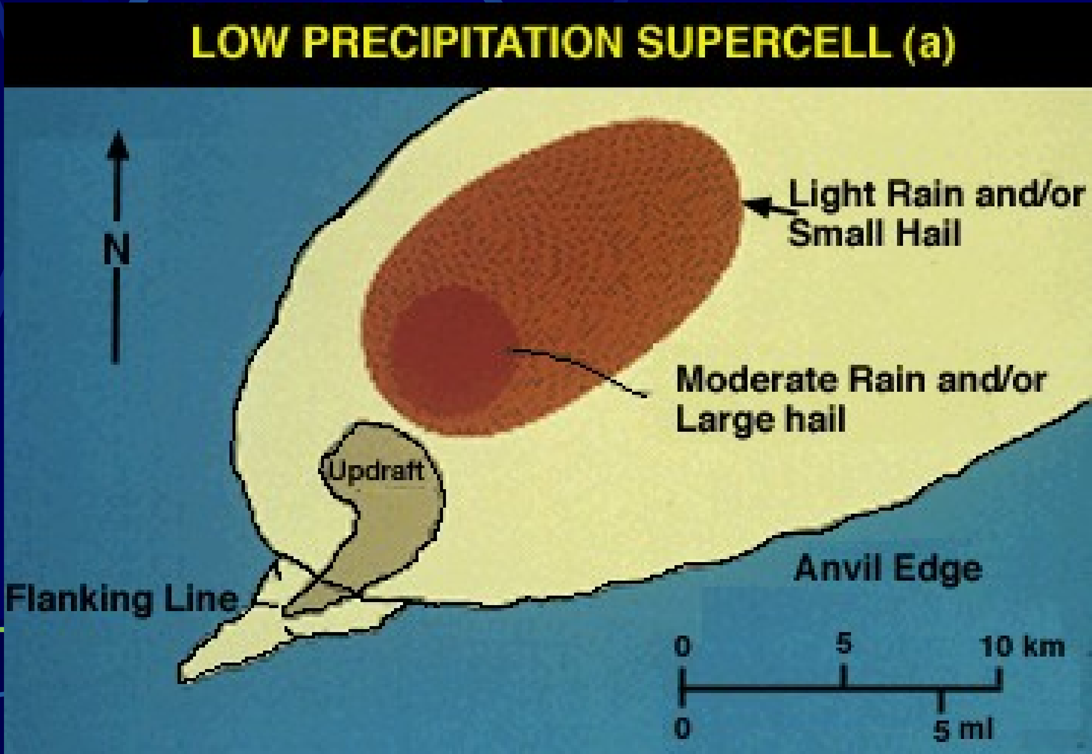
A multiple-vortex tornado had just dissipated from beneath this distant updraft, and an opaque precipitation shaft was developing in the previously rain-free area where the tornado occurred.

Low Precipitation (LP) Supercells

lacking in liquid rainfall content

At the opposite end of the supercell scale is the Low Precipitation (LP) supercell. For years, storm chasers have observed LP storms in the Plains' states, usually in conjunction with a dry line or low pressure trough dividing dry, warm air to the west from very humid air to the east. These rotating storms typically are quite small and lacking in liquid rainfall content.

The radar echo rarely contains a pendant or hook, although the LP storm may have a tight reflectivity gradient at the southwest side. In many cases, the small size of the storm will not allow for adequate "beam filling", especially at moderate to long range from the radar. Therefore, the



This northward view of an LP storm in western Oklahoma shows both the small size and the powerful nature of the updraft. This storm was shrinking to an even smaller size at this time, which is how most LP storms meet their demise. Note that the updraft tower is scarcely any wider than the wall cloud. The storm earlier produced golf ball size hail and, although it rotated vigorously, it did not produce any tornadoes.

Low-precipitation supercells probably rarely occur, if at all, east of the Mississippi River. They frequently produce large hail, funnel clouds, and wall clouds, and occasionally spawn weak or even strong tornadoes. Radar identification of the storm as a supercell is difficult, especially at great range, because of the relatively small size and dry nature of the storm. Similar to the classic supercell, but unlike the HP storm, severe

LOW PRECIPITATION SUPERCELL

- LP storms have very few "classic" radar signatures and some classic visual signatures
- Weather events can include:

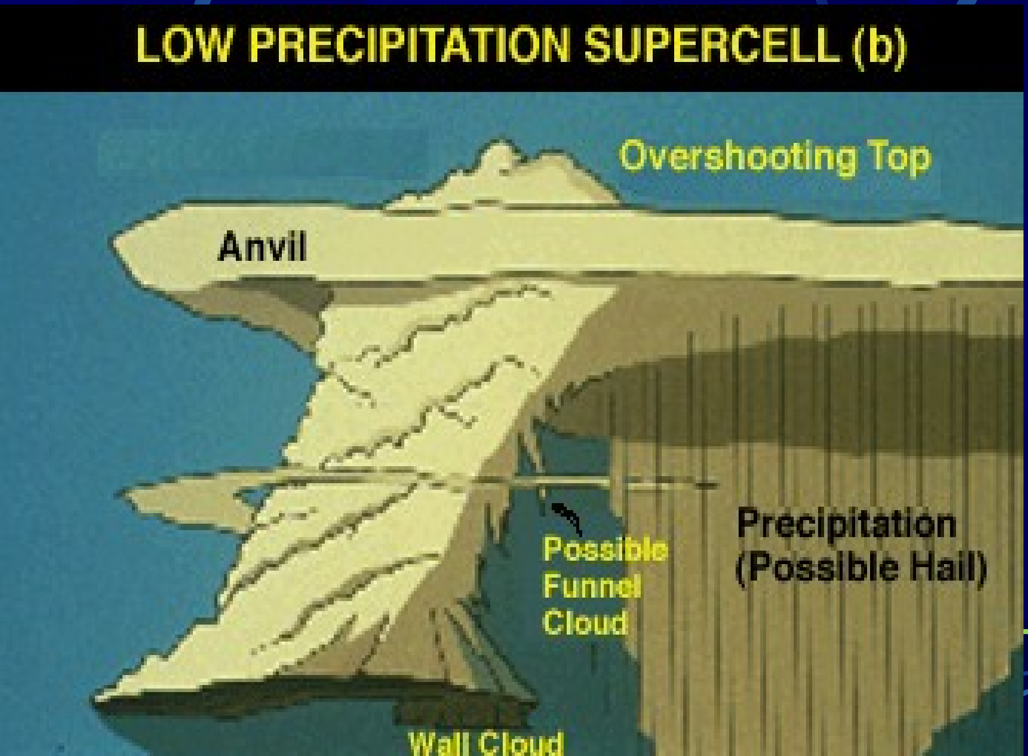
  Large hail
  Weak and occasional strong tornadoes
  Weak to moderate intensity downdrafts
  Scanty rainfall
- Severe events typically occur on the rear (southwest or west) storm flank

One last point of discussion for radar operators: spotters may report very wild visual sights and large hail with one of these storms while radar shows very little. Diplomacy, not disbelief, is important, for if you work severe weather in Texas, Oklahoma, Kansas, Nebraska, the Dakotas, or eastern portions of Colorado and Wyoming, you will encounter the LP supercell sooner or later.

LP Supercell With Tornado

plus rotating cloud bands and vaulted appearance

A westward view of the LP storm model's vertical cross-section shows the LP storm's undersized, rotating Cb and its small, nearly transparent precipitation area. Rotating cloud signatures are commonly visible in this supercell type, and wall clouds are frequently observed.



An oddity is that this bare-bones storm type occasionally fosters small funnel clouds that extend from the mid-levels of the Cb rather than from the Cb base! At times weak or even strong tornadoes develop from the vicinity of the wall cloud.

This LP storm did produce tornadoes -- two of them. The storm actually bordered between an LP and a classic supercell as it has a fairly large and intense radar echo (VIP 5), including a pendant. In this westward view, we note that the wall cloud was on the north side of the rain-free base, with spectacular rotating bands arranged much like barber pole stripes around the parent Cb.

This view gives us an excellent feel for the scale relationships between the rotating updraft and the tornado that occasionally develops beneath such an updraft. Remember, the radar hook echo is roughly equivalent in scale to the rotating Cb, whereas the tornado itself is much smaller.

The same storm is pictured looking northwest, as the tornado was lifting/weakening into a funnel cloud (extreme lower left). The storm has a spectacularly vaulted appearance adjacent to the precipitation area, which was nearly transparent. Scattered raindrops were falling in this precipitation area, along with 5 inch diameter hail! Thus, the lack of an opaque precipitation curtain does not preclude the possibility of very damaging hail.

This storm produced about 5 million dollars in hail damage in Borger, Texas, with one rain gauge that survived the hail fall showing only 1/4 of an inch of liquid rain. The tornado that we have witnessed in these photographs produced several hundred thousand dollars damage to an oil refinery, and several injuries.

Evolution From Multicell To Supercell

multiple updrafts merge into a single updraft

This late afternoon New Mexico storm has subtle indications of being multicellular. Can you see the two major updraft areas? You cannot always discern between storm types by visual observations. Radar usually is the best tool for that purpose, but in many cases the visual appearance will yield important clues.

This is the same storm complex less than one our later. The multicell complex apparently has evolved into a storm with one dominant updraft. The storm has become a supercell.

The storms we have seen lead us to ask several fundamental questions: What environmental factors influence the type or types of storms and the intensity of severe weather that occurs on a given day? And why does a storm sometimes evolve from one type to another?

Tornadic Supercell

produced six tornadoes

This supercell did produce tornadoes, six of them. About the time this photograph was taken, the last of the six tornadoes was occurring. From this vantage point about 20 miles north of the storm, near Itasca, Texas, we see a small portion of the rain-free base beneath the updraft area, but no tornado. Obviously, a spotter must have the right position r [partially hidden] es.

The same storm and its sixth tornado were photographed in a different location at about the time the last photo was taken. Looking northeast from 4 miles, we are on the other side of th

t photo.

The left to right moving condensation funnel is partially illuminated by late afternoon lighting. Note the sharp-edged precipitation curtain on the right side. The combination of strong and adjacent vertical drafts often results in very heavy hail and rain curtains immediately downwind (usually northeast) of the updraft. Indeed, spotting position does make a difference, although the